ASSESSMENT OF LIGHT DUTY GASOLINE VEHICLE EMISSIONS INSPECTION AND MAINTENANCE PROGRAM OPTIONS FOR THE LOWER MAINLAND AREA

TASK FORCE REPORT
TO
THE LOWER MAINLAND OXIDANTS STEERING COMMITTEE

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PREFACE

In late 1985 the Lower Mainland Oxidants Steering Committee set up a Task Force on Motor Vehicle Emission Inspection/Maintenance (I/M) to examine the feasibility of an I/M program for the Lower Mainland of British Columbia.

The terms of reference for the study included (i) identification of I/M program options for the area by reviewing the existing programs in other jurisdictions, in particular where the private industry plays a key role, and (ii) an analysis of the anticipated benefits and preliminary costs associated with each option. A brief report in the format of a Cabinet Submission was submitted in May 1986.

The Task Force consisted of the following members:

Jacalyn Hamilton	Ministry of Environment and Parks
Phillip Toogood	Ministry of Transportation and Highways
Morris Mennell	Greater Vancouver Regional District
Doug Cope	Environment Canada
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The Steering Committee requested Kamal K. Bhattacharyya of the Ministry of Environment and Parks in July 1986 to prepare a detailed technical report based on the available information and input from the Task Force members.

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SUMMARY

The Lower Mainland of British Columbia is recognized as one of the areas in the country with potential problems of photochemical oxidants pollution. Elevated levels of ozone, a measure for photochemical oxidants, have been experienced in the region in recent years. As a part of the framework for ozone control strategies, the Lower Mainland Oxidants Steering Committee in 1984 had recommended that the feasibility of a motor vehicle emission inspection and maintenance (I/M) program be examined. Subsequently a Task Force was set up to identify I/M program options, particularly those where private industry plays a key role, and to provide an analysis of the anticipated benefits and preliminary costs associated with each option.

The findings of the investigation by the Task Force are presented in this document. It provides brief background information on emissions of photochemical oxidant precursor contaminants and on the relevant air quality situation in the area. The characteristics of the motor vehicle emissions, the types of available emission control technology, and the potential increase in emissions due to malmaintenance, tampering and misfueling are also discussed. A summary of all existing and proposed I/M programs in the U.S.A. is provided along with descriptions of the major features of these programs. The potential emission reductions due to introduction of new federal emission standards, for 1988 and later model years, and several types of I/M program have also been estimated. On the basis of the above, an I/M program for the area has been outlined, and recommendations made for several supplementary measures as well as further activities for the final design of the program.

Because of the lack of pertinent information, no cost-benefit analysis of the suggested I/M program has been possible. It has been recommended that such analysis should be carried out at the detailed program design stage.

A detailed inventory of emissions for the Lower Mainland area is currently being prepared. Accordingly, the estimates of emissions of oxidant precursors from various sources in the study area has been prorated from a broad province-wide inventory, and the data presented here should be considered as very preliminary. It appears that the emissions of hydrocarbons and nitrogen oxides, the main precursors of oxidants formation, from automobiles constitute approximately 30% of the total emissions from all sources and 60% of that from mobile sources.

Even though new motor vehicles are designed and manufactured to emit pollutants at or below the federal emission standards over their useful life, various tests have shown that emissions from some in-use vehicles often exceed those limits. The increased emissions are found to be in excess of that associated with normal deterioration of the engine and related components. Instead, the causes of such high emissions are identified to be maladjustments, tampering with emission control systems, and/or misfueling of vehicles designed to use unleaded fuel.

The federal government has introduced more stringent emission standards for 1988 and later model year automobiles and light duty trucks. These standards are similar to those in effect in the U.S.A. since 1981 for similar vehicles.

The major impact of the new emission standards is expected to be that instead of traditional mechanical-pneumatic engine parameter control devices in older vehicles, most new vehicles will be equipped with more recent and complex control systems. These include micro-processor based electronic controls, various sensors, fuel injection systems, and catalytic converters to control exhaust emissions. It is anticipated that the new technology vehicles will be subject to less tampering and maladjustment by the owners or mechanics. The experience in the U.S.A. indicates that although the new control systems result in more precise engine and emission control, any malfunction due to improper maintenance, tampering and/or misfueling can turn these vehicles into very high emitters. For example, by habitual misfueling of vehicles equipped with three-way catalytic converters, the emissions of total hydrocarbons (THC), carbon monoxide (CO) and nitrogen oxides (NO_x) can increase by 4-5 times, 2-3.5 times, and 1.5-2 times respectively. Thus a relatively small number of vehicles can have a large impact on the total fleet emissions.

The primary purpose of an I/M program is to ensure that it acts as an effective deterrent to tampering, misfueling and malmaintenance. In the U.S.A. the Environmental Protection Agency (EPA) considers the I/M program as one of the strategies for reducing emissions from in-use vehicles, and is widely applied in air quality non-attainment areas. The conventional I/M program primarily involves an exhaust emission analysis. However, in recent years EPA has approved certain programs which are mainly based on anti-tampering and misfueling (a test for the presence of lead in the exhaust pipe) inspection (ATP) only. To achieve additional benefits in emission reductions, EPA has lately been encouraging inclusion of some form of ATP in the existing conventional I/M programs.

There are several major features of an I/M program which are designed on an area-specific basis to suit the particular local objectives. The emission reductions that could be achieved by implementing an I/M program depend on certain existing conditions in the area, namely the emissions from the motor vehicles, the fleet characteristics, and tampering and misfueling rates among others, as well as on the design and enforcement of the program. For the Lower Mainland area there is a lack of reliable information on most of the items necessary for proper design of a program and estimation of emission reductions achievable.

However, an attempt has been made to estimate the potential reductions in emissions which could be achieved by implementing an I/M, ATP and I/M plus ATP types of program in the Lower Mainland. It should be noted that these estimates are very crude and be treated accordingly. In the absence of any reliable local data on most parameters, various default values developed by EPA have been used to generate emission factors by the computer program MOBILE 3C. The impacts of new emission standards and several scenarios of I/M programs on the emissions of THC, NO_x and CO in the Lower Mainland have been determined. The emission estimates are based on the preliminary emission inventory data for 1980 and on the assumptions that the vehicle population will grow by 2% per annum and there will be no additional emissions from the other sources during the period until the year 2000.

It has been estimated that the introduction of new emission standards will result in reduction of emissions of THC by 48%, NO_x by 26%, and CO by 37% from the base year of 1986 to the year 2000. These reductions in vehicular emissions will correspond to a decline in total area-wide emissions of

20% for THC, 6% for NO_x, and 19% for CO during the same period. The estimates also indicate that depending on the type of I/M program implemented, additional reductions in total emissions of 3-7% for THC, 0-1% for NO_x, and 3-15% for CO in the area may be achieved by the year 2000. It has been estimated that for each percentage reduction in the misfueling rate could result in 0.1% decline in the area-wide THC emissions during the period 1988-1993.

After reviewing the available information on various I/M programs, particularly with respect to control of ozone precursor emissions, a mandatory decentralized ATP type I/M program has been suggested for the Lower Mainland area. Because of the many uncertainties involved in the implementation of such a program and due to the lack of necessary information for a detailed design, a phased approach to its introduction is considered to be the most appropriate. Hence, only the general outlines of the major program features have been provided in this report.

A phased approach would provide opportunities for an extensive public relations campaign, mechanic training program, and for collection of data necesssary for the final design and cost-benefit analysis for the program.

Several supplementary measures, mostly of legislative nature, which should be taken to enhance the program effectiveness have also been suggested for due consideration along with the recommendations for further activities.

1. INTRODUCTION

In recent years, the Vancouver-Lower Fraser Valley (Lower Mainland) area in British Columbia has been experiencing photochemical oxidants pollution, as indicated by the high levels of ozone in the atmosphere. At certain times of the year the ozone concentration in the area still exceeds the maximum acceptable level of the National Ambient Air Quality Objectives. Ozone is known to cause adverse effects on human health and vegetation. A large segment of the population of the province resides in the area, and the period of high ozone level occurrences also coincides with the growing season for agricultural crops in the rural outskirts. Hence, the area is recognized as one of the potential ozone problem areas in the country[1].

In August 1984, the Lower Mainland Oxidants Steering Committee, represented by Environment Canada, Ministry of Environment (now Ministry of Environment and Parks), and the Greater Vancouver Regional District, made certain recommendations on ozone control plans[2]. One of the recommendations for immediate action is that the feasibility of a motor vehicle emission inspection and maintenance (I/M) program for the area be examined. The then Minister of Environment announced in December 1984 that the Lower Mainland area would be the location for the first comprehensive ozone control strategy in the country[3]. Early in 1985 the Greater Vancouver Regional District Board also urged the Provincial authorities to implement an I/M program[4]. Throughout the period Environment Canada has been providing active support in developing an ozone control program for the area.

One of the major sources of precursor contaminants responsible for ozone formation in urban areas is the motor vehicle. Numerous studies have shown that due to frequent maladjustments, disablements, misfueling and failures of emission control systems, the resulting emissions from motor vehicles are often many times that of the design standards. These excess emissions of oxidant precursors could be reduced by controlling such tampering and misfueling activities.

A Task Force consisting of members from all three levels of government was set up in late 1985 to carry out the feasibility study for an I/M program. The terms of reference for the study included (i) identification of I/M program options for the area by reviewing the existing programs in other juridictions, in particular where the private industry plays a key role, and (ii) an analysis of the anticipated benefits and preliminary costs associated with each option.

Although originally the Task Force was required to prepare a Provincial Cabinet Submission based on its findings, because of a revised mandate the Task Force submitted its report to the Steering Committee in June 1986. The latter, however, subsequently requested the Task Force to prepare a more detailed technical report for its consideration.

In preparing this report the major reliance has been placed on the available information on the various I/M programs in the U.S.A., as the problem of photochemical oxidants is prevalent in various urban areas in that country. For a proper perspective of the situation and an understanding of the complex problem, it is considered appropriate to provide briefly the status of the air quality and emissions in the area, the current knowledge on the photochemical oxidants formation, and the characteristics of the motor vehicle emissions prior to reviewing the various aspects of the I/M programs. Unfortunately, no detailed cost-benefit analysis of an I/M program for the Lower Mainland has been carried out due to the limited time. However, it is expected that such information will be available from a study[5] currently being carried out for Environment Canada.

2. EMISSIONS OF OXIDANTS PRECURSORS AND AIR QUALITY IN THE LOWER MAINLAND

To provide a proper perspective of the oxidants problem in the Lower Mainland area, the available information on the emission rates of major precursors for oxidants from various sources is summarized below. The ambient air quality data for ozone, nitrogen oxides, carbon monoxide and total hydrocarbons from the monitoring stations in the area are also presented to emphasize the need for some control strategies.

2.1 Emissions of Oxidants Precursors

An emission inventory is not currently available for the Lower Mainland. However, estimates of emissions have been provided by the Inventory Management Division of Environment Canada for 1980, which are presented in Table 2.1. The nationwide inventory of air contaminants prepared by Environment Canada[6] is based on point specific provincial statistics. This information was subsequently prorated using Statistics Canada census data to supply the regional or city emission estimates. No relevent regional parameters were factored into the regional estimates, hence it should be understood that such an approach can only provide a crude approximation of the emissions in the Lower Mainland and may not be precise enough for any detailed emission inventory necessary for an oxidants control program.

Using this Environment Canada inventory, ratios have been developed to indicate the contribution of air contaminants to the atmosphere from automobiles, as shown in Table 2.2.

TABLE 2.1

Estimated Emissions in the Lower Mainland, 1980
(Tonnes)

Source Sector	Major Oxidant Precursors		CO
	THC	NOx (as NO_2)	
POINT SOURCES:			
Electric Power Generation	8	1,601	122
Petroleum Refining-Fuel Combustion (+ incineration)	23	1,914	751
Petroleum Refining - Process	8,293	372	40,435
Sewage Sludge Incineration	2	6	-
Others	60	-	1,082
Sub-Total	8,386	3,893	42,390
AREA SOURCES:			
Gasoline Marketing	8,079	-	-
Diesel Powered Engines	3,632	36,666	10,268
Fuel Combustion (Stationary Sources)	524	8,823	2,669
Gasoline Powered Vehicles			
• automobiles	22,120	16,385	211,955
• heavy duty trucks	4,688	3,548	71,202
• light duty trucks	5,465	5,162	75,665
• medium duty trucks	4,562	3,562	53,770
• other	1,567	30	3,868
General Solvent Use	4,283	-	-
Others	16,563	8,810	51,394
Sub-Total	71,483	82,986	480,791
Solid Waste Landfills[1]	98,647		
TOTAL	178,516	86,879	523,181

[1]. THC emissions from solid waste landfills consist of approximately 99.7% methane and ethane[7].

Source: 6

TABLE 2.2

Contributions from Mobile Sources and Automobiles to Total Emissions

Contaminant	Year	Stationary Sources Total (tonnes)	Mobile Sources Total (tonnes)	$\frac{\text{Mobile Sources}}{\text{Stationary Sources}}$	$\frac{\text{Automobiles}}{\text{All Sources}}$	$\frac{\text{Automobiles}}{\text{Mobile Sources}}$
THC	1980	41,467 (140,114)	38,402	0.93 (0.27)	0.28 (0.12)	0.58
NOx (as NO_2)	1980	58,192	28,687	0.49	0.19	0.57
CO	1980	106,721	416,460	3.90	0.41	0.51

(   ) Including the emissions from landfills

Because of the data limitations definitive conclusions based on these ratios are inappropriate at this time, however, emissions from the automobiles appear to represent about half of the total emissions from mobile sources. The Transportation Systems Division of Environment Canada is now using the US EPA Mobile 3 model, modified for the Canadian vehicle fleet, to establish vehicle emission rates which should provide emission estimates more relevent to Canadian vehicles and to the Lower Mainland.

A detailed inventory of emissions for the study area is presently being prepared. It is expected that more precise information will then be available as compared to that derived from the national inventory.

2.2 Air Quality in the Lower Mainland

The Lower Mainland (Vancouver-Lower Fraser Valley) of British Columbia has been recognized as one of the most affected areas in the country with oxidants problem[1,2]. Air quality and meteorological monitoring data from the area for the years 1978 to 1984 have recently been analyzed to determine any influence of the meteorological factors on the ozone levels [8-11]. For the purpose of this report no review of these studies is done, but only the air quality monitoring data for ozone and its main precursors have been extracted to show the trends. The above data, however, have been supplemented by the information available from the Ministry of Environment and Parks (MOEP) data archive and the Greater Vancouver Regional District (GVRD)[12-13].

The sources of air quality data are the monitoring networks of the GVRD, MOEP and the National Air Pollution Surveillance (NAPS). A location map of the currently operating monitoring stations is presented in Figure 2.1. It should be noted, however, that as not all stations were established at the same time, the trend results should be treated with caution.

The exceedances of ozone (O_3), nitrogen dioxide (NO_2) and carbon monoxide (CO) have been determined on the basis of the corresponding National Ambient Air Quality Objectives (NAAQOs), shown in Table 2.3, as there are no such Provincial objectives except for CO. There are no NAAQOs for total hydrocarbons (THC).

2.2.1 Trend in Ozone Levels

Various statistics for ozone exceedances and episodes are provided in Tables 2.4 - 2.6, and illustrated in Figure 2.2. The major features appear to indicate that during the period 1978-1985 the ozone levels in the area climbed to a peak in 1981, dropped significantly in 1983, but started to increase since then.

No definite reasons, such as meteorological factors or emission related activities, were provided in the report[4] for the decline in O_3 levels during 1983. It should be noted, however, that the statistical analysis might have been influenced by the monitoring results from one particular stations T7 and T9, considered to be the locations of frequent O_3 exceedances, where the sudden decline in O_3 levels occurred in 1983. According to Faulkner[15], the O_3 level at the particular location of T9 is likely to be influenced by the precursor emissions from the local refinery.

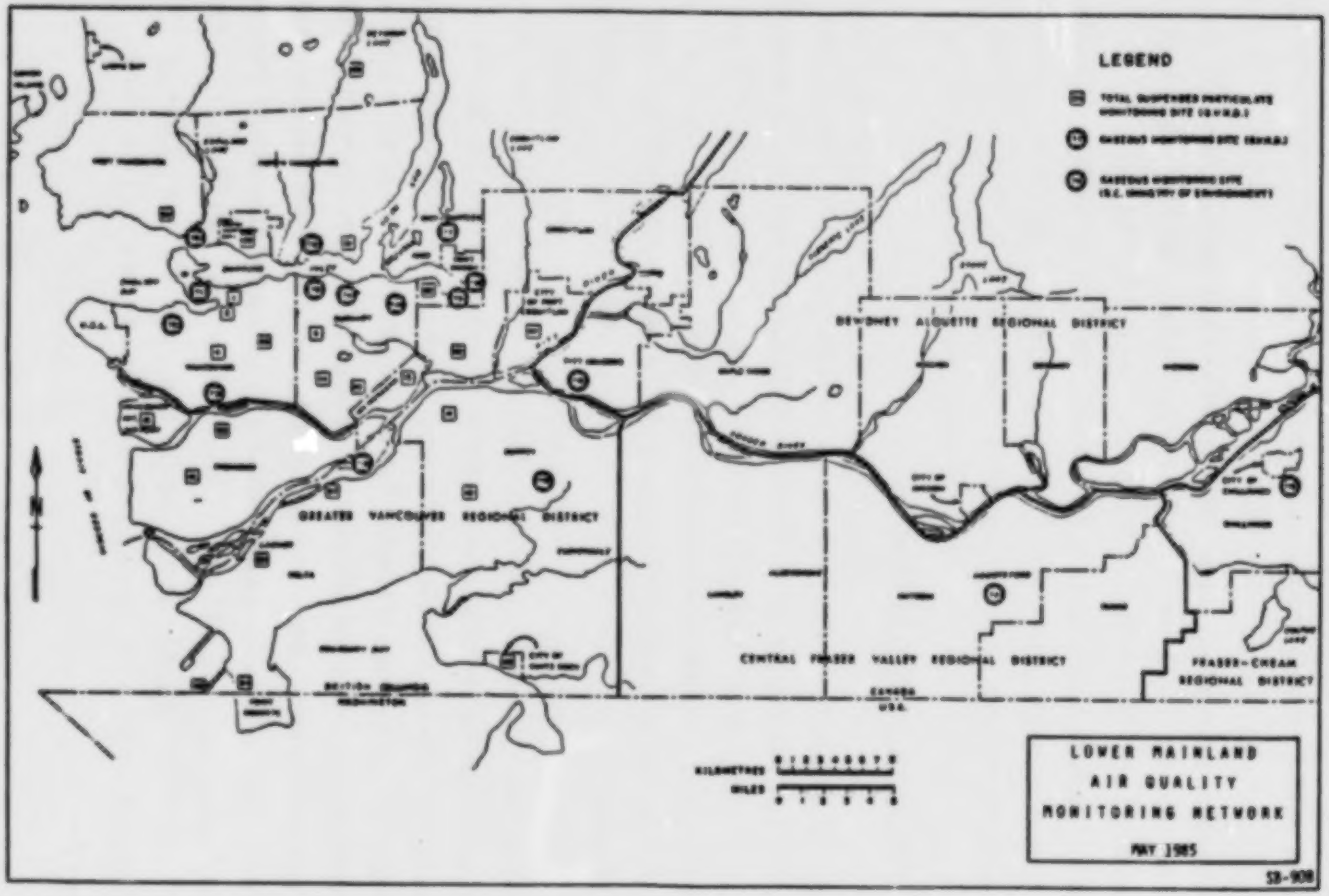

LEGEND
TOTAL SUSPENDED PARTICULATE MONITORING SITE (G.V.R.D.)
GASEOUS MONITORING SITE (G.V.R.D.)
GASEOUS MONITORING SITE (B.C. MINISTRY OF ENVIRONMENT)
GREATER VANCOUVER REGIONAL DISTRICT
DEWDNEY ALOUETTE REGIONAL DISTRICT
CENTRAL FRASER VALLEY REGIONAL DISTRICT
FRASER-CHEAM REGIONAL DISTRICT
CANADA
U.S.A.
KILOMETRES
MILES
LOWER MAINLAND
AIR QUALITY
MONITORING NETWORK
MAY 1985
SB-908

FIGURE 2.1: Location Map of Currently Operating Air Quality Monitoring Stations

TABLE 2.3

National Ambient Air Quality Objectives for Carbon Monoxide, Nitrogen Dioxide, and Oxidants.

Air Contaminant	Maximum Desirable Level	Maximum Acceptable Level	Maximum Tolerable Level
Carbon Monixide			
Average 1-hour concentration	13 ppm (15 mg/m^3)	31 ppm (35 mg/m^3)	-
Average 8- hour concentration	5 ppm (6 mg/m^3)	13 ppm (15 mg/m^3)	17 ppm (20 mg/m^3)
Oxidants (ozone)			
Average 1-hour concentration	0.05 ppm (100 µg/m^3)	0.08 ppm (160 µg/m^3)	0.15 ppm (300 µg/m^3)
Average 24-hour concentration	0.015 ppm (30 µg/m^3)	0.025 ppm (50 µg/m^3)	-
Annual arithmetic mean	-	0.015 ppm (30 µg/m^3)	-
Nitrogen Dioxide			
Average 1-hour concentration	-	0.21 ppm (400 µg/m^3)	0.53 ppm (1000 µg/m^3)
Average 24-hour concentration	-	0.11 ppm (200 µg/m^3)	0.16 ppm (300 µg/m^3)
Annual arithmetic mean	0.03 ppm (60 µg/m^3)	0.05 ppm (100 µg/m^3)	-

Concentrations are corrected to a reference temperature of 25°C and 760 mm of Hg.

Source: 14

TABLE 2.4

Summary of Ozone Monitoring Data, 1978-1985

Parameter	Year							
	1978	1979	1980	1981	1982	1983	1984	1985
Total Number of 1-h Average Values Exceeding 0.08 ppm*	256	278	318	466	178	59	61	144
Maximum Recorded Level:								
1-h Average, ppb**	182(T10)	175 (T9)	245(T9)	265(T7)	160(T7)	169(T9)	107(T9)	124(T9)
24-h Average, ppb**	74(T7)	63(T7)	87(T7)	75(T7)	70(T7)	71(T9)	54(T10)	60(T15)
Annual Arithmetic Mean, ppb**	22(T7)	24(T7)	26(T7)	26(T7)	23(T7)	21(T14)	20(T10&T11)	
Number of Stations Showing Exceedances of:								
1-h Average (>0.08 ppm)	9	12	11	8	8	4	10	11
24-h Average (>0.025 ppm)	11	12	13	12	14	13	15	17
Annual arithmetic Mean (>0.015 ppm)	4	3	4	5	7	4	4	
Total Number of Stations	11	12	14	13	15	14	16	17

* At all stations

** Station identification numbers are given in parantheses

Source: 8, 9, 12, 13

TABLE 2.5

Statistics on Ozone Exceedances and Episodes, 1978-1985

Parameter	Year							
	1978	1979	1980	1981	1982	1983	1984	1985
Station Exceedances	81	83	91	120	55	14	24	53
Station Episodes	44	45	48	71	26	8	9	
Exceedance Days	39	43	61	54	42	11	9	
Episode Days	24	24	34	34	23	5	2	
Areal Episodes	6	5	2	11	0	0	2	
Persistent Episodes	2	1	0	2	0	0	0	

Station Exceedance - The occurrence of one or more 1-hourly average ozone value >0.08 ppm on a given day at a particular station.

Station Episode - The occurrence of three or more available consecutive 1-hourly average ozone values >0.08 ppm at a station on a given calendar day.

Areal Episode - The occurrence of station episodes at three or more stations on the same calendar day.

Persistent Episode - The occurrence of areal episodes on at least any two of three consecutive calendar days.

Exceedance Days and Episode Days are defined respectively as calendar days on which one or more station exceedance or one or more station episode occurs.
Source: 9, 12

TABLE 2.6

Monthly Station Exceedances and Station Episodes, 1978-1985
(Ozone Level)

YEAR	JAN.		FEB.		MAR.		APR.		MAY		JUN.		JUL.		AUG.		SEPT.		OCT.		NOV.		DEC.		TOTALS	
	Ex	Ep	Ex	Ep	Ex	Ep	Ex	Ep	Ex	Ep	Ex	Ep	Ex	Ep	Ex	Ep	Ex	Ep	Ex	Ep	Ex	Ep	Ex	Ep	Ex	Ep
1978	0	0	0	0	0	0	0	0	2	1	22	13	32	17	19	13	0	0	4	0	0	0	2	0	81	44
1979	0	0	0	0	0	0	7	5	11	6	18	9	20	12	18	9	9	4	0	0	0	0	0	0	83	45
1980	2	1	0	0	1	0	11	8	14	9	8	4	22	8	13	10	12	6	7	2	0	0	1	0	91	48
1981	0	0	0	0	4	0	3	2	5	0	3	1	20	10	56	41	27	17	2	0	0	0	0	0	120	71
1982	0	0	0	0	3	0	2	2	17	12	12	5	3	2	11	3	7	2	0	0	0	0	0	0	55	26
1983	0	0	0	0	0	0	0	0	6	4	0	0	6	4	2	0	0	0	0	0	0	0	0	0	14	8
1984	0	0	0	0	0	0	0	0	0	0	0	0	13	4	10	5	1	0	0	0	0	0	0	0	24	9
1985	0	-	0	-	0	-	0	-	4	-	8	-	36	-	5	-	0	-	0	-	0	-	0	-	53	-

Ex - Station Exceedances, Ep - Station Episodes, - Not determined

Source: 9, 12

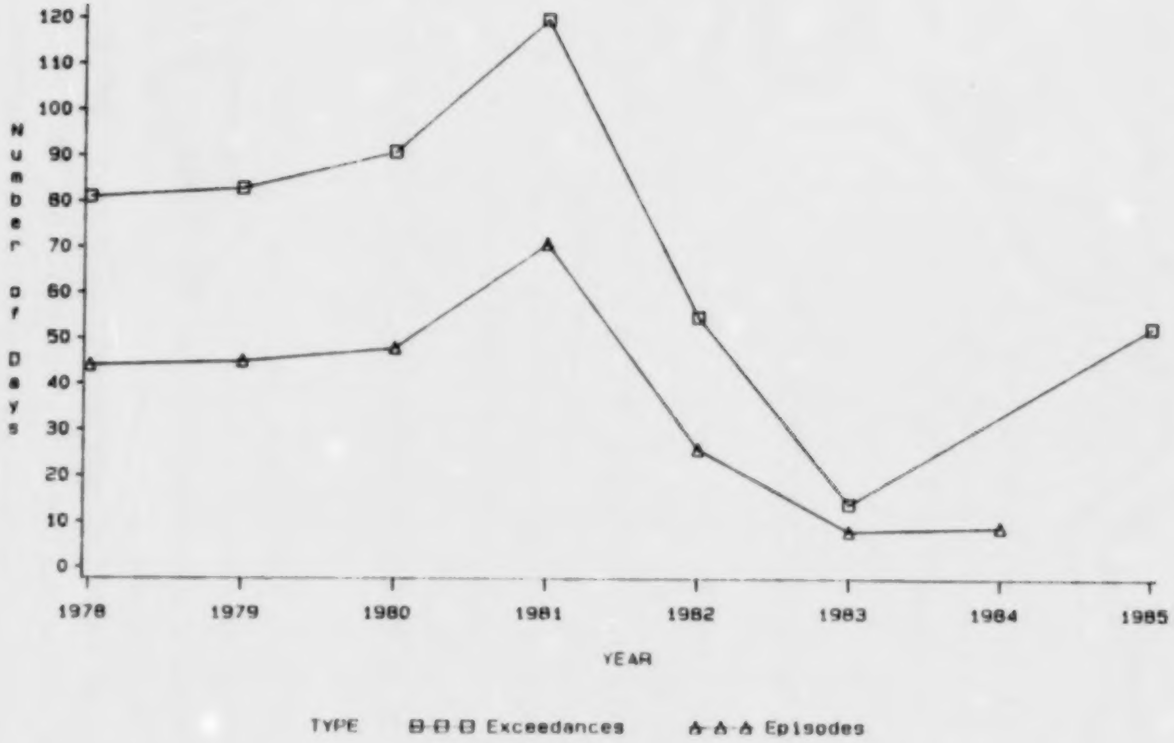


FIGURE 2.2: Number of Station Exceedances and Station Episodes For Ozone During 1978-1985

Source: 9, 12

The exceedances were observed to be restricted to a few particular monitoring stations. With the exception of a few incidences, almost all exceedances occurred during the period of May to September, the so-called traditional ozone season. The spatial distribution of O_3 values indicate that the exceedances did occur, somewhat infrequently, at two westerly and downwind stations in rural areas.

The analysis of diurnal variations in O_3 levels indicates that all hourly maximum concentrations were recorded between the hours of 10:00 and 18:00 in the urban areas and later at the rural stations downwind.

2.2.2 Trend in Total Hydrocarbon Levels

Only a limited number of data from a few stations are available for THC concentrations in the area. The annual mean 1-hour values, as shown in Table 2.7, do not indicate any definite trend on an area-wide basis. There is no information available on the reactive hydrocarbons levels, which is more relevant to the oxidants problem, in the area.

2.2.3 Trends in Nitrogen Dioxide and Total Nitrogen Oxides Levels

A summary of the available data for nitrogen dioxide monitoring is presented in Table 2.8. It appears that the 1-h maximum acceptable level of the NAAQO was exceeded once in 1979 and five times in one day in 1984, but at different locations. The 24-h maximum acceptable level of the NAAQO was exceeded twice during 1984 as well as in 1985. These exceedances occurred at different monitoring stations, but on each occasion the exceedances were on consecutive calendar days.

TABLE 2.7

Annual Mean 1-Hour Total Hydrocarbons Concentrations

Station	Annual Mean (ppb)*					
	1979	1980	1981	1982	1983	1984
T7	3253 (69)	2579 (58)	2399 (94)	2567 (91)	2375 (82)	2994 (80)
40	-	2367 (35)	1586 (16)	-	-	-
T2	2667 (86)	2672 (95)	2460 (60)	2358 (93)	2294 (86)	2351 (90)
T4	-	2275 (2)	2741 (60)	2530 (74)	3027 (43)	2451 (78)
T9	3563 (18)	2653 (69)	2059 (60)	2773 (81)	2835 (86)	3057 (72)
Area Mean †	2994	2639	2412	2551	2579	2695

* = Numbers in parenthesis are the percent of possible daily observations for the year

- = Not available. Station not in operation.

† = Area mean for stations T7, T2, T4 and T9 weighted by data recovery.

Source: 8, 9

TABLE 2.8

Summary of Nitrogen Dioxide Monitoring Data, 1977-1985

Parameter	Year								
	1977	1978	1979	1980	1981	1982	1983	1984	1985
Total Number of 1-h Average Values Exceeding 0.21 ppm*	0	0	1 (1 day)	0	0	0	0	5 (1 day)	0
Total Number of 24-h Average Values Exceeding 0.11 ppm*	0	0	0	0	0	0	0	21 (2 days)	27 (2 days)
Maximum Recorded Level:									
1-h Average**	0.20(T4)	0.21(T1)	0.25(T7)	0.19(T6)	0.20(T1)	0.20(T7)	0.14(T6)	0.27(T1)	0.18(T3)
24-h Average**	0.09(T4)	0.11(T1)	0.08(T7)	0.07(T1)	0.08(T6)	0.10(T9)	0.08(T3)	0.13(T1)	0.13(T3)
Number of Stations Showing Exceedances of:									
1-h Average (>0.21 ppm)	0	0	1	0	0	0	0	1	0
24-h Average (>0.11 ppm)	0	0	0	0	0	0	0	1	1
Total Number of Stations	7	9	10	10	10	10	10	14	15

* Total number of rolling average values (number of calendar days) at all stations.

** Station identification numbers are given in parantheses

Source: 8, 9, 12

The data for the total nitrogen oxides concentrations for the years 1982 to 1985 are tabulated in Table 2.9. All 1-h and 24-h maximum concentrations, except the 24-h value in 1984, occurred at the same location.

The majority of the peak concentrations for both NO_2 and NO_x occurred during the period from September to May in each year.

2.2.4 Trend in Carbon Monoxide Levels

The available data from 1977 to 1985 for the carbon monoxide levels are summarized in Table 2.10. There has been no exceedance of the 1-h maximum acceptable level of the NAAQO during that period. The 8-h concentration exceeded the NAAQO maximum acceptable level on seven days at two stations in 1985 only. Most of the peak values were observed during the period from September to February in each year.

TABLE 2.9

Summary of Total Nitrogen Oxides
Monitoring Data, 1982-1985

Parameter	Year			
	1982	1983	1984	1985
Maximum Recorded Concentration (ppm):				
1-h Average*	0.90(T3)	0.93(T3)	0.94(T3)	0.99(T2)
24-h Average*	0.52(T3)	0.50(T3)	0.70(T1)	0.66(T3)

* Station identification number is given in parantheses

Source: 9, 12,

TABLE 2.10

Summary of Carbon Monoxide Monitoring Data, 1977-1985

Parameter	Year								
	1977	1978	1979	1980	1981	1982	1983	1984	1985
Total Number of 1-h Average Values Exceeding 31 ppm*	0	0	0	0	0	0	0	0	0
Total Number of 8-h Average Values Exceeding 13 ppm*	0	0	0	0	0	0	0	0	25 (7 days)
Maximum Recorded Level:									
1-h Average	20(T3)	19(T2)	25(T2)	16(T2)	31(T1)	17(T2)	16(T2)	17(T2)	29(T1)
8-h Average	13(T2)	13(T2,T3)	13(T2)	10(T1)	16(T1)	13(T2)	9(T2)	11(T3)	17(T1)
Number of Stations Showing Exceedances of:									
1-h Average (>31 ppm)	0	0	0	0	0	0	0	0	0
8-h Average (>13 ppm)	0	0	0	0	0	0	0	0	2(T1,T2)
Total Number of Stations	9	9	10	10	10	10	10	13	13

* Total number of rolling average values (number of calendar days) at all stations.

** Station identification numbers are given in parantheses

Source: 12, 13

3. PHOTOCHEMICAL OXIDANTS AND OZONE CONTROL STRATEGIES

Photochemical oxidants are unique atmospheric pollutants in that these are not emitted as such from any specific sources. It is recognized now that these secondary pollutants are the products of complex chemical reactions involving several precursors under favourable atmospheric conditions. The major precursors are the primary pollutants such as nitrogen oxides and a class of reactive hydrocarbons. The atmospheric conditions conducive to the photochemical reactions are bright sunlight, high temperature and low humidity[16, 17].

Ozone (O_3) is the most abundant photochemical oxidant, and it usually represents about 90% of the total oxidants[11]. As air quality objectives relating to oxidants are basically directed to O_3 concentration and it can be measured more readily than other photochemical oxidants, its concentration is used to indicate the severity of the oxidant problem. Most of the studies on photochemical smog problem to date have also dealt with the possible ozone formation mechanisms in the atmosphere as a surrogate for all types of oxidants[17].

Ozone is also one of the natural constituents of both the stratosphere and troposphere. While it is generated in relatively high concentrations in the stratosphere by ultraviolet radiation from the sun, its concentration in the clean tropospheric atmosphere at remote locations varies from 0.02 to 0.08 ppm on a monthly average basis[18].

The incidences of photochemical air pollution was first identified as early as 1945 around Los Angeles area, and in several other urban areas of the world since then[16, 17]. Beginning with the pioneering work of A.J. Haagen-Smit in the early 1950s numerous investigations to date have established the basic mechanisms of the photochemical phenomenon[16-28]. Until the 1970s it was believed that ozone formation would primarily be a typical problem in urban areas. However, during the last decade the presence of high concentrations of ozone in areas many kilometres downwind from urban sources has also been identified[17, 21-25, 29-32].

Some components of the photochemical oxidants group are known to cause visibility reduction, eye irritation and plant damage[16, 17]. Ozone has been known to cause damage to man-made materials, for example, rubber cracking, dye fading and paint weathering[33-36]. It is now recognized that ozone also causes adverse effects on human health and damages to forestry vegetation and agricultural crops[16, 17, 33-36]. Studies on the effects of ozone on human health to date indicate that it is an exceptionally potent agent, but the effects of long-term exposure to ozone are yet to be determined[35-36].

3.1 Formation of Ozone

For a secondary pollutant such as ozone, which results from primary pollutant precursors in relatively short time and is aided by atmospheric conditions, the development of precise control strategies to reduce its ambient concentrations is significantly more difficult than for other contaminants. The control strategies for ozone are, therefore, limited to only the controllable parameters, namely the sources of anthropogenic emissions of precursor pollutants As mentioned earlier, the major precursors are reactive hydrocarbons and nitrogen oxides. Carbon monoxide is also known to take part in photochemical reactions, but when hydrocarbons are present it does not appear to play any significant role in the oxidant formation[37].

Despite the recognition of the major precursors, the exact contributions of these contaminants towards ozone fromation remain unresolved because of the complex photochemical reactions involved. A brief review of the recent studies on the subject is considered necessary for a proper appreciation of the inherent difficulties in designing an ozone control strategy.

As regards as the terminologies for the major ozone precursors, throughout the text the term HC is used to mean total volatile organic compounds (VOC) excluding methane (CH_4), and the commonly used term NO_x is used to represent the total of nitric oxide (NO) and nitrogen dioxide (NO_2). The total hydrocarbons, THC refers to (VOC + CH_4).

3.1.1 The HC-NO_x-O_3 Relationship

In the absence of other reactive species, when NO_x is present in the atmosphere, O_3 is formed by photolysis of NO_2 according to the following reactions:

$$NO_2 + h\nu \rightarrow NO + O \qquad (1)$$

$$O + O_2 + M \rightarrow O_3 + M \qquad (2)$$

As there are no significant O_3 emissions, the above reactions are considered to represent its only major source[17]. However, the O_3 thus formed is relatively short-lived, as it reacts rapidly with NO, either already present or produced by reaction (1), to regenerate NO_2:

$$O_3 + NO \rightarrow NO_2 + O_2 \qquad (3)$$

When no other interfering species are present, a photostationary state is achieved for O_3 formation[17, 38, 39].

The ratio of NO_2/NO, therefore, is a determining factor of any O_3 build-up. It is also evident that if the proportion of NO is higher than NO_2 in a mixture, no excessive O_3 generation can take place, if NO is not oxidized to NO_2 by any means other than reaction (3).

In an atmosphere containing an excess of organic compounds, especially organic radicals (RO_2), NO is oxidized to NO_2 and other free radicals are also generated at the same time:

$$NO + RO_2\cdot \rightarrow NO_2 + RO\cdot \qquad (4)$$

Thus a cycle of reactions (1), (2) and (4) continues with regeneration of NO_2 and production of O_3 without being destroyed by reaction (3)[16, 17, 19, 36]. Various smog chamber and modeling studies on the interactions of $HC\text{-}NO_x\text{-}O_3$ tend to confirm the above relationship[19, 21, 24-31, 40].

It appears from the above that where the HC is in excess supply, NO_x will react with HC to generate NO_2, which in turn will produce more O_3, rather than scavenging O_3. Under such conditions, by limiting the NO_x supply the production of O_3 can be reduced more effectively than by controlling HC emission. However, in areas where insufficient amount of HC is present for reacting with the available NO_x, O_3 will be scavenged by the remaining NO_x. In such cases, HC control will be effective in reducing O_3 as more NO_x will be available to destroy O_3. Any reduction of NO_x may, however, lead to less scavenging of O_3. Thus the ratio of HC/NO_x emissions in an area appears to be another significant factor in developing an ozone control strategy.

3.1.2 Effects of HC and NOx Emissions Control on O_3 Level

During the last two decades in addition to the research on ozone photochemistry, numerous "real world" investigations on the effects of precursor emission control on ozone levels have been carried out. These studies, mostly in the U.S.A., have encompassed several aspects of the problem such as air quality trend analysis, meteorological factors, photochemical modeling and control of specific precursor emission in various locations affected by high ozone levels. As an elaborate review of these investigations is beyond the scope of this report, only the major observations on this seeming paradoxical problem are presented below.

There appears to be a general consensus in the scientific community, at least from the photochemistry standpoint, on the influence of both HC and NO_x emissions on the O_3 generation. However, the disagreement seems to surround the specific roles of the precursor ratios HC/NO_x and NO_2/NO in NO_x, which are critical in developing O_3 control strategies. Some of the basic reasons for the controversy are the paucity of credible long-term air quality trend studies, changes in the ozone monitoring techniques, questionable statistical means of data analysis, and uncertainties in the precursor inventories[41].

It is now generally recognized that a reduction in anthropogenic HC emissions results in a decrease in the O_3 level[16, 17, 19-28, 41]. Several investigators have suggested that a reduction in HC/NO_x ratio by decreasing HC emissions and/or increasing NO_x emissions is probably a reasonable O_3 control strategy at least for the immediate source area[19, 23-28]. Any control of NO_x emissions is reportedly counterproductive in the reduction of O_3 in urban areas[19,26-28,41].

Recent field observations have, however, indicated that while some reductions in urban O_3 levels might have been achieved by controlling precursor emissions, the O_3 level in certain downwind rural areas has been observed to increase[18-19,22-28,32]. Several modeling studies have also suggested such increases in rural O_3 level when the NO_x emissions upwind are controlled along with HC[19,21,36,42,43].

The estimated impact of changes in HC and NO_x emissions on both urban and rural peak as well as average O_3 concentrations have been determined by the Environmental Protection Agency (EPA) in the U.S.A., using different state-of-the-art models[36]. The ranges of these estimates as well as the point values are presented in Table 3.1. The states in the U.S.A. with ozone non-attainment problem are also required to submit to the EPA their State Implementation Plans (SIPs) as part of ozone control strategies. A list[43] of the proposed SIP design bases for selected cities indicating the relationship between estimated THC and O_3 reductions is shown in Table 3.2.

After analyzing all these data the EPA's Office of Air Quality, Planning and Standards has suggested that on average, a 1% reduction in THC would reduce urban O_3 by 0.6%, and this ratio is considered to be the best estimate[36].

TABLE 3.1

Estimated Ozone Reduction Due to Reductions in Volatile Organic Compounds and Nitrogen Oxides Emissions in Urban and Rural Areas

1% Reduction of Contaminant Emission	% Reduction in O_3 Concentration		
	Urban O_3	Average Rural O_3	Peak Rural O_3
VOCs			
In Urban VOCs	0.60	0.13	0.05
In Rural VOCs	0	0.04 to 1.13 (0.07)[a]	0.05 to 0.20 (0.01)[a]
No_x			
In Urban No_x	-0.05 to -0.30 (-0.1)[a]	-0.09	-0.10 to 0.10 (0.04)[b]
In Rural NO_x	0	0.05 to 0.24 (0.15)[a]	0.05 to 0.24 (0.15)[a]

(a) Estimates varied by a fairly wide range. Point estimates appear in parenthesis.

(b) Sparse evidence does not permit estimation of a single point estimate with a reasonable degree of certainty. In many areas (the Northeast Corridor) wind trajectories would probably transport metropolitan ozone to other urban centers or over the ocean. In these cases, rural ozone would not change. In other areas, however, the increased ozone from urban NO_x reductions would travel to rural areas. But, lower rural NO_2 levels would reduce ozone. Therefore, the overall effect could be positive or negative. We assume that a one percent uniform reduction in metropolitan No_x reduces rural ozone by 0.04 percent.

Source: 35

TABLE 3.2

Estimated Ozone Reductions from One Percent Reduction in Volatile Organic Carbons Emissions for Selected Cities in the U.S.A.*

City	$\frac{\%\ O_3\ \text{Reduction}}{\%\ \text{VOC Reduction}}$
Boston, MA	0.7
New York, NY (NY-NJ-CT)	0.9
Philadelphia, PA (PA-NJ-DE)	0.8
Baltimore, MD	0.7
Washington, DC (DC-MD-VA)	0.9
Houston, TX	1.4
St. Louis, MO	0.7
Salt Lake City, UT	0.8
Los Angeles, CA	0.9
Fresno, CA	0.8
Ventura, CA	0.7
San Diego, CA	1.1

* From SIP design data. Modeling parameters current as of April 21, 1983; emission inventory current as of February 1983.

Source: 43

According to Dimitriades and Altshuller[32], the increase in the natural O_3 level in rural atmosphere may be due to a combination of the following phenomena: (i) transfer of O_3 from the stratosphere, (ii) local photochemical generation from precursors of indigenous and/or urban sources, and (iii) transport of O_3 from urban areas. Singh, et al[18] have reported that although the estimates of O_3 flux from the stratosphere to troposphere are uncertain, mass exchange between the two atmospheric layers does take place depending on the natural conditions. This phenomenon, however, is uncontrollable to a large extent. The direct transport of O_3 from upwind areas is site-specific and depends on the local meteorology.

Both major precursors of O_3 are emitted from natural sources in relatively higher quantities in rural areas than in metropolitan centres[18, 44-48]. However, it has been reported that contributions of natural HC and NO_x emissions to O_3 formation are relatively insignificant under most atmospheric conditions[18, 42-44].

Regarding the possible local synthesis of O_3, two plausible explanations have been provided in the literature - the "dual role" of NO_x and the dilution of the reaction system. It is evident from the previous sections that NO_x acts as a promoter and an inhibitor of O_3 formation. According to Graedel, et al[24], O_3 level appears to depend on the absolute NO_x concentration as well as on the NO_2/NO ratio. O_3 generation becomes more efficient at lower concentrations of the precursors[18, 21, 23, 41, 44].

It appears, therefore, that for an overall reduction of the ozone level on a regional basis, it may be prudent to design control strategies for both HC and NO_x. For the Lower Mainland area, reduction of both HC and NO_x emissions has been suggested by Environment Canada as the most effective approach[1]. Such a program is also likely to contribute towards the improvement of the receiving environment from adverse effects of both the primary and secondary pollutants.

3.2 Ozone Control Strategies and Motor Vehicle Emissions Inspection and Maintenance Program.

It is obvious from the information presented in the previous sections that an ozone control strategy has to be based on the reduction of emissions of its major precursors, HC and NO_x. Nearly all sources of carbonaceous fuel combustion emit both HC and NO_x to a varying degree, and this category may be the largest contributor of these contaminants in most urban areas. The other major sources of HC emissions are petroleum refining, storage and handling of petroleum products, manufacturing of petrochemicals, and various uses of organic solvents. Besides the combustion sources, NO_x are emitted only from a few chemical manufacturing processes.

In the U.S.A., where a large number of urban areas are coping with the ozone problem, under Section 172 of the Clean Air Act the affected states have been required to develop control strategies for the reduction of precursor emissions, primarily the emission of reactive hydrocarbons[43]. The states must consider all potential HC sources and implement all "reasonably available" and any other control measures necessary for attaining the air quality standard for ozone within the specified date. Although the final selection of the specific sources for HC control is dependent on the types of sources prevalent in a given area and the cost-effectiveness of various control measures, the mobile sources are designated as one of the prime candidates for consideration. Amongst the eighteen categories of transportation control measures included in Section 108(f) of the Clean Air Act, the major one is the emission inspection and maintenance (I/M) program for the motor vehicles[43, 49].

Motor vehicles, the most common mobile source, produce both HC and NO_x and contribute significantly towards the total emission flux in an urban area. The emissions of these O_3 precursors also take place close to ground level. Presently, automobiles seem to contribute nearly half of the emissions of each major precursor from the mobile sources in the Lower Mainland. As for the future projection, it has been estimated that, even after introduction of the more stringent motor vehicle standards in September 1987, in the next 10 to 15 years the THC and NO_x emissions in the area may increase and thus result in an increased O_3 level[10].

Approximately 78% of the THC emitted from the automobiles is reported to be of reactive types which take part in ozone formation[50, 51]. An I/M program is a strategy which attempts to reduce the vehicular emissions by providing an incentive to the vehicle owners for proper maintenance. Hence in the absence of a reliable and detailed emission inventory, the recommendation of the Steering Committee for an investigation into the feasibility of a motor vehicle emission I/M program is appropriate as one of the immediate control measures for ozone.

4. MOTOR VEHICLE EMISSIONS

Until the recognition of the motor vehicles as the major contributors to the atmospheric pollution, the vehicles were designed primarily to optimize power and driveability. The exhaust emissions of contaminants from those vehicles without any pollution control devices were extremely high. Because of the increasingly stringent emission standards, the manufacturers have, over the years, redesigned various components of the internal combustion (IC) engines and introduced sophisticated emission control systems in motor vehicles. These efforts have resulted in vehicles which are capable of emitting less than 10% of the THC and CO and about 25% of the NO_x levels of the uncontrolled vehicles of the mid-1960 models[52, 53]. It should be noted, however, that the in-use vehicles on the road often emit these contaminants much in excess of the designed levels because of a variety of factors related to the IC engine operation and emission control systems. Prior to discussing these factors it is considered appropriate to describe briefly the operation of an IC engine and the generation of contaminants emitted therefrom.

4.1 Internal Combustion Engine and Vehicle Emissions

Light duty gasoline vehicles are most commonly powered by carbureted, spark-ignited, four-stroke, Otto-cycle internal combustion engines[16, 17, 54]. The basic operating cycles are schematically shown in Figure 4.1. A piston moves up and down within the engine cylinder, delivering the power through a connecting rod to the crankshaft, which drives the vehicle through an appropriate drive train.

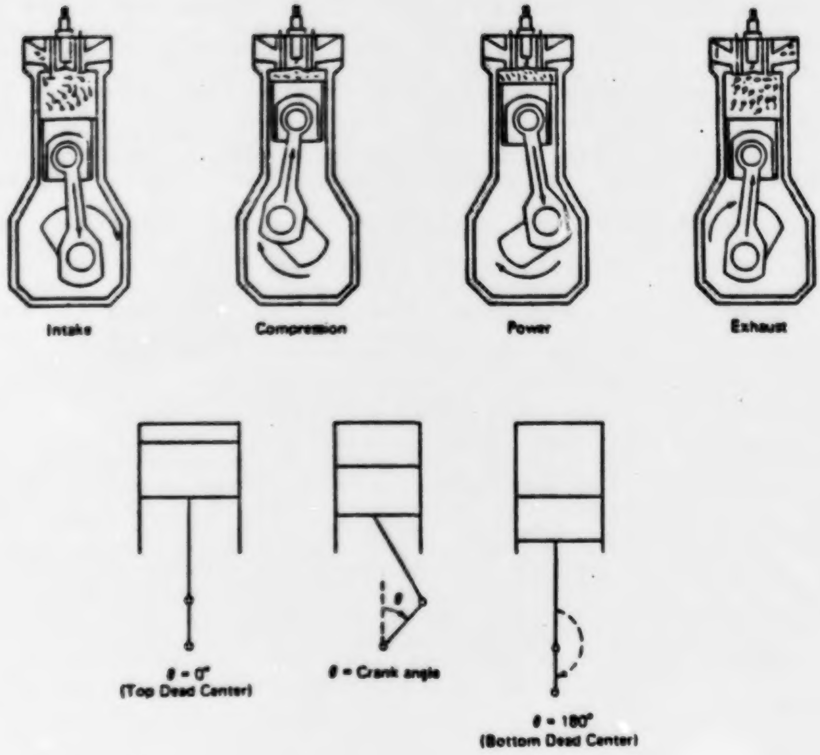

Intake
Compression
Power
Exhaust
θ = 0°
(Top Dead Center)
θ = Crank angle
θ
θ = 180°
(Bottom Dead Center)

FIGURE 4.1: Basic Operating Cycles of a Four-Stroke, Spark-Ignited Internal Combustion Engine

The four strokes of the Otto-cycle engine are:

Intake - The descending piston draws the charge of fuel/air mixture in the cylinder through the open inlet valve.

Compression - The rising piston compresses the charge against closed valves towards the top of the cylinder where the spark plug sparks to start the combustion.

Expansion - As the fuel/air mixture burns, the expanding combustion products force the piston down and deliver the power.

Exhaust - The exhaust valve opens as the piston rises, and the products of combustion are forced out of the cylinder.

The carburetor provides the correct air/fuel mixture for the best performance and fuel consumption at different vehicle speed and load range. In order to be combustible, the air/fuel ratio on a weight basis must be within a range of 9 to 20; the mixture is incombustible below or above this range[16,17,54]. The best power output, as during acceleration, is obtained at slightly low air/fuel (rich in fuel) ratios. However, the best fuel economy is achieved with mixtures having air/fuel ratios slightly higher (lean in fuel) than the stoichiometric ratio, which is reported to be about 14.5 for typical gasoline[16,54]. As illustrated in Figure 4.2, the air/fuel ratio is one of the important factors which governs the characteristics of the vehicle exhaust emissions.

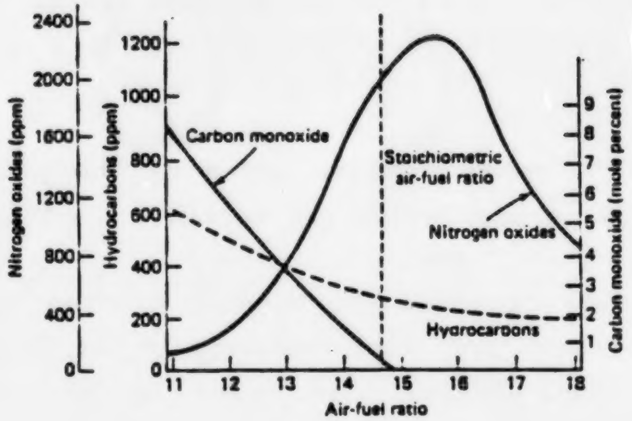


FIGURE 4.2: Exhaust Emissions of Hydrocarbons, Carbon Monoxide, and Nitrogen Oxides as a Function of Air-Fuel Ratio

Source: 17

4.1.1 Vehicle Emissions

The emissions from motor vehicles are usually characterized into three basic types[16, 54-56]. which are briefly discussed below.

1. Trip-related Emissions - These consist of vehicle startup and hot soak emissions. There are two types of startup emissions, namely, cold start and hot or hot transient.

   Cold Start Emissions - These emissions occur within the first 505 seconds of a start after the engine has been turned off for 4 hours or more, in the case of noncatalyst-equipped vehicles, or for 1 hour or more for catalyst-equipped vehicles.

   Hot Start (Hot Transient) Emissions - These emissions are those that occur roughly within the first 505 seconds of a start after the engine has been turned off for less than 1 hour. Hot start emissions are associated within catalyst-equipped vehicles only, and are also significantly less than cold start emissions.

   Hot Soak Emissions - These emissions are evaporative hydrocarbon losses that occur from the carburetor as a result of the engine shut down, primarily within the first hour after engine off.

2. Travel-related Emissions - These emissions occur in the hot stable operating mode after the vehicle has warmed up past the cold/hot start mode, and are commonly known as exhaust emissions.

3. Vehicle-related Emissions - The vehicle-related emissions are evaporative hydrocarbon losses from the fuel tank due to changes in ambient temperature during the day. These losses are also known as diurnal emissions.

The above emissions are affected by various factors, some of which are inter-dependent. These factors are the vehicle make and model year, its condition, the types of emission control devices installed, the driving habit, the vehicle speed, and the type of road. The relative magnitudes of the emissions of THC, CO and NO_x as affected by some of these factors are shown in Table 4.1.

4.2 Vehicle Emission Control Technology

Motor vehicle manufacturers have been developing emission control systems since the 1960s to comply with the increasingly stringent emission standards in many countries. One of the cornerstones of a vehicle emission inspection and maintenance (I/M) program is the effectiveness of the performance of various emission control devices in the motor vehicles. Therefore, it is essential that the basic principles behind these emission control systems are understood and appreciated. It is intended to provide only the outlines of these principles here, leaving the detailed discussion on any of the items relevant to the I/M program for later sections as appropriate.

There are basically four ways by which the emissions of THC, CO and NO_x can be reduced[54, 55, 57]:

1. Engine modifications
2. Exhaust emissions treatment
3. Fuel modifications
4. Fuel evaporation control

TABLE 4.1

Effect of Vehicle Driving Mode on Emissions

Condition		Exhaust				Crankcase Blowby[1] Rate[2]	Fuel System[3] Evaporation Rate[2]	
Vehicle	Engine	Rate	Concentration					
			THC	CO	NO_x		Tank	Carburetor
Idle	Operating	Very low	High	High	Very low	Low	Average to Moderate	Moderate
Cruise								
Low speed		Low	Low	Low	Low	Moderate		Small
High speed		High	Very low	Very low	Moderate	High		Nil
Acceleration								
Moderate		High	Low	Low	High	Moderate		Nil
Heavy		Very high	Moderate	High	Moderate	Very high		Nil
Deceleration		Very high	Very low	High	Very low	Very low		Moderate
Hot Soak	Stopped	None	-	-	-	None	High	High
Diurnal		None	-	-	-	None	Moderate	Very low

[1] - Concentration of THC is high, CO low and NO_x very low.
[2] - Flows are at least one order of magnitude lower than the exhaust flow.
[3] - For a vehicle not equipped with an evaporative emission control system.

Source: 54

4.2.1 Engine Modifications

The engine modification systems include those features of the conventional IC engines which can be implemented to reduce emissions without the need for any redesigning of the actual engine. As the primary aim is to reduce generation of these contaminants without any undue sacrifice of fuel economy and driveability, the manufacturers have incorporated devices to achieve more efficient combustion of the fuel in the engine. Although the details of the engine modifications design vary, the major features shared essentially by all versions include a combination of some or all of the following:

- controlled fuel-air mixture ratio,
- improved charge distribution,
- refined control of spark timing,
- controlled burning of the charge,
- exhaust gas recirculation, and
- regulated injection of secondary air into the exhaust manifold.

Unfortunately, while most of these changes result in reduced levels of THC and CO, some of them affect the NO_x emission adversely. Conversely, some measures for NO_x reduction do increase the emissions of THC and/or CO[16, 17, 54-59].

The first engine modification to reduce vehicle emission started in North America with the introduction of emission standards in California in 1963 for the control of engine crankcase blow-by emissions[54, 55]. The manufacturers introduced positive crankcase ventilation system to recycle the blow-by to the engine for combustion. Thus the emissions caused by crankcase blow-by are now part of the exhaust emissions, although mostly as the combustion products.

4.2.2 Exhaust Emissions Treatment

To meet more stringent exhaust emission standards of 1972 in California, and that of 1975 in the rest of the U.S.A., the manufacturers introduced catalytic converters to treat the exhaust gas[54, 55]. Initially, this post-combustion treatment of exhaust gas was aimed mainly at controlling THC and CO by oxidizing these constituents in the presence of a catalyst. Subsequently, however, to meet the NO_x emission standards, particularly for six and eight-cylinder vehicles, catalytic after-treatment of NO_x also became necessary[55, 57]. As opposed to oxidation of CO and THC, NO_x requires chemical reduction to nitrogen and oxygen. The manufacturers have since then introduced systems commonly known as three-way catalysts. There are variations of these systems, but fundamentally some catalysts can perform, to a certain extent, as oxidation, reduction or both under proper reaction atmosphere and conditions. These systems include single-bed and dual-bed, the latter requiring secondary air injection between the beds.

The catalysts used in the converters are extremely susceptible to deactivation by leaded fuel. This is one of the reasons of emphasis by the regulatory agencies on controlling the use of lead additives in gasoline fuel, the other being to reduce lead emission from motor vehicles. As a result of catalyst deactivation, its conversion efficiency is reduced significantly, and the pollutants are emitted in increased quantities depending on the extent of catalyst poisoning. This important aspect of exhaust treatment will be discussed in later sections.

4.2.3 Fuel Modifications

Although the use of fuels other than gasoline is possible, the following discussion is restricted to modifications to gasoline composition only. In general, the engines burning fuels containing large quantities of highly reactive hydrocarbon fractions emit through the exhaust system hydrocarbons with correspondingly high reactivity[51, 54, 58]. The composition of fuel also governs the fuel volatility to a large extent, which in turn significantly affects the total quantity of fuel evaporation losses from motor vehicles[16, 17, 51, 54, 56-58].

To control emissions of the more reactive species of hydrocarbons, such as unsaturated olefins, from evaporative sources, it has been suggested that saturated paraffins may be substantiated for the reactive species without affecting the volatility[54]. Generally the petroleum industry uses saturated paraffins, mainly butanes and pentanes, to maximize gasoline volatility[54, 58, 60], and evaporative HCs are reportedly dominated by these compounds[51, 54]. Such substitution does not appear to affect THC, CO and NO_x emission through the vehicle exhaust in any significant manner, although catalytic converters are more effective in reducing unsaturated, hydrocarbons than the saturated fractions[51, 54]. Because of the particular significance of evaporative hydrocarbon losses in an area with an oxidant problem, the subject of fuel volatility will be dealt with separately in a subsequent section.

As a result of the growing concern about the use of tetraethyl lead (TEL) as an anti-knock additive both as a health risk and its adverse effects on catalytic converters, an alternative substance methylcyclopentadienyl manganese tricarbonyl (MMT) is being used by the petroleum refiners in Canada.

In the U.S.A., the use of MMT has been disallowed since 1978 by EPA[57, 61], presumably on the ground that it adversely affects the vehicle exhaust emissions, in particular that of

THC. Recent investigations by the Canadian General Standards Board (CGSB), however, have indicated that the use of MMT at the current level (0.0165 g Mn/L) does not have any significant impact on the tailpipe hydrocarbon emissions[61]. Test results have shown that the average increase in the exhaust THC emission over "clear" fuel should range from 0.03 to 0.11 g/mile for the 1988 MY vehicles. CGSB has also reported that the MMT use at the above level does not appear to affect the emission control system in any significant manner, although the effects of a prolonged use require investigation[61].

4.2.4 Fuel Evaporation Control and Fuel Volatility

Fuel evaporative emissions occur mainly from the vehicle fuel tank and carburetor. The crankcase blow-by emissions also consist of about 85% unburned fuel/air micture[17]. Evaporative emissions are a function of fuel vapour pressure and surrounding temperature. These emissions consist entirely of hydrocarbons of reactive nature. Since the early 1970's evaporative emission control systems have been installed in vehicles[55]. Basically the systems include a trap and evaporative storage, which prevents the hydrocarbon losses mentioned above. Further reduction in evaporative emissions can be achieved by using fuels of low vapour pressure[51, 54, 58].

Gasoline volatility has a direct impact on the quantity of hydrocarbons emitted from in-use vehicles, in particular that of reactive hydrocarbons through evaporative emissions. The latter increases as the fuel volatility and/or the ambient temperature increase.

4.2.4.1 Gasoline Volatility and Composition

These two properties of gasoline are to a large extent interrellated, as a gasoline is a mixture of four basic types of hydrocarbon compounds with different boiling points. The hydrocarbon groups are paraffins, olefins, naphthenes and aromatics. To meet commerical requirements the refiners can select a blend of these compounds and produce the gasoline of the desired quality[60]. One of the most important quality of gasoline used in internal combustion engines is its volatility, which is defined as its tendency to transform from the liquid to vapour state.

For satisfactory performance of a conventional internal combustion engine, the gasoline must:

- evaporate readily enough to supply a combustible fuel-air charge to the cylinder when the engine is started cold. It must also be sufficiently volatile during normal running, when the engine is warm, without causing any problem with liquid in the intake manifold;

- the gasoline should not be so volatile as to cause carburetor icing during cold weather, or to create vapour lock in the fuel delivery system when the engine is hot;

- it must burn smoothly and quietly in the cylinder without knocking or detonation; and

- the fuel must evaporate completely and cleanly without leaving deposits in the fuel supply system and in the engine.

In the case of a mixed product such as gasoline, the lower-molecular-weight compounds have a greater vapourizing tendency, and thereby contribute more to the vapour pressure than do the higher-molecular-weight fractions, which have higher boiling points. As the gasoline is depleted of lighter fractions by evaporation, its vapour pressure decreases.

Gasoline volatility is characterized in three ways according to the standard procedures of the American Society for Testing and Materials (ASTM), the procedures also followed by the Canadian Government Specifications Board (CGSB) in prescribing National Standard of Canada[62, 63]. These are vapour pressure, vapour-liquid ratio, and the distillation characteristics. Each of these volatility measures can be related to vehicular emissions; however, the most commonly used one is the Reid Vapour Pressure (RVP). The RVP is the measure of the vapour pressure of the fuel at 37.8°C (100°F) and a volumetric ratio of vapour:liquid is 4:1.

4.2.4.2 Gasoline RVP Standards and Trend in Commercial Gasoline RVP

After due consideration of the vehicle driveability in all seasons the regulatory agencies usually specify gasoline volatility in terms of RVP for summer and winter. These standards for Canada, as specified by CGSB, are shown in Table 4.2. The monthly variation of the typical gasoline RVP sold in the Vancouver area is illustrated in Figure 4.3, and it ranges from 10.4 psi RVP to 12.0 psi RVP[64].

The FTP used by EPA in certification program for vehicular evaporative emissions specifies the test fuel RVP values from 8.7 to 9.2 psi[51, 58]. The emission factor developed by the EPA to estimate vehicular emissions from different model year vehicles are based on computer programs MOBILE 2 (for earlier model years) and MOBILE 3 (later model years). The fuel RVPs assumed in these programs are 9 and 11.5 psi for MOBILE 2 and MOBILE 3 respectively[68, 69].

No information on the trends in commercial gasoline volatility in this country is readily available. However, in the U.S.A. the national average gasoline RVP has shown steady increase since 1946 for both summer and winter grades[51, 58]. During this period the summer grade gasoline RVP has

TABLE 4.2

Canadian Standards for Gasoline RVP

Gasoline Type	RVP, kPa (psi)			
	Summer		Winter	
	Min.	Max.	Min.	Max.
Automotive Type 1 and Type 2	-	76 (11.02)	62 (8.99)	97* (14.07)
Automotive, Unleaded Type 1 and Type 2	-	76 (11.02)	62 (8.99)	97* (14.07)

* The 97 kPa maximum limit applies to the winter grades of both Types 1 and 2 fuel in the months of October, March and April. During the interval 1 November to 28 February inclusive the maximum RVP may be increased but shll not exceed 103 kPa (14.94 psi).

Source: 62

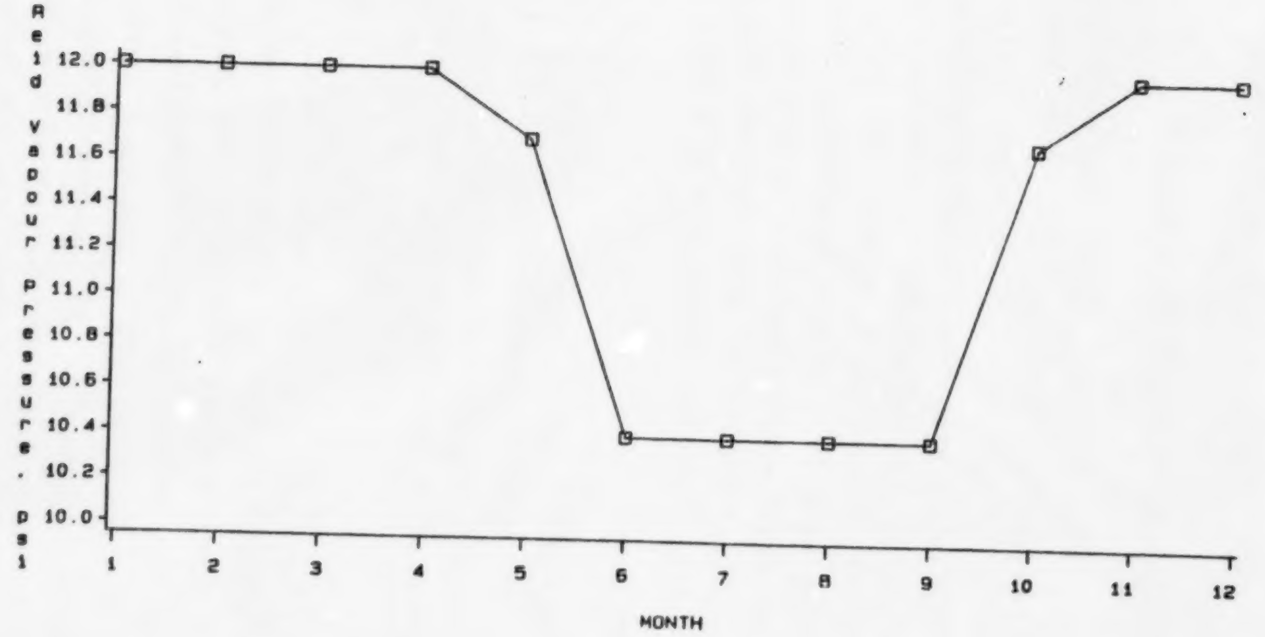


FIGURE 4.3: Typical Monthly Gasoline Vapour Pressure in Vancouver Area 1979-1980

Source: 64

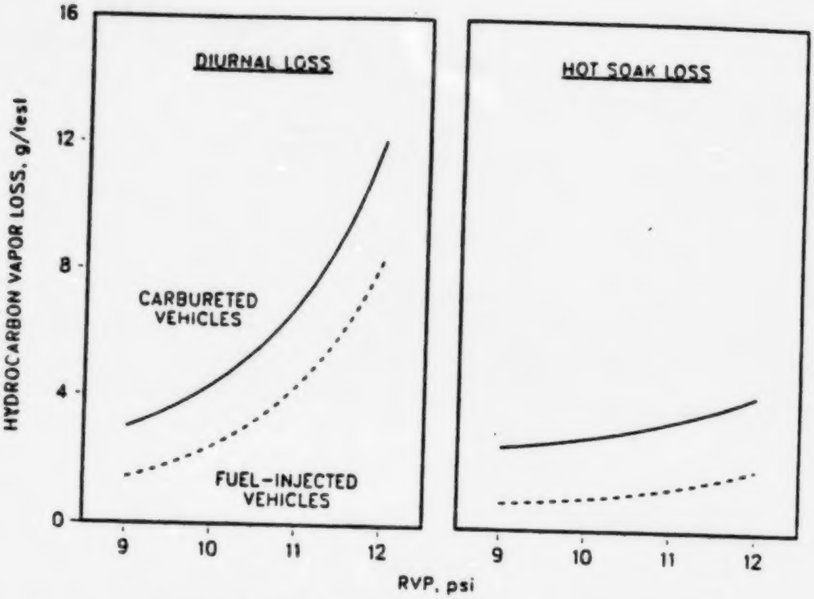
increased gradually from about 7.0 to 10.2 psi in 1984. The winter gasoline RVP has shown similar increase from about 10 to 13.8 psi in the same period. It has been reported[58] that since 1980 the RVP of unleaded regular gasolines of both grades has increased substantially.

4.2.4.3 Gasoline Volatility and Emission Characteristics

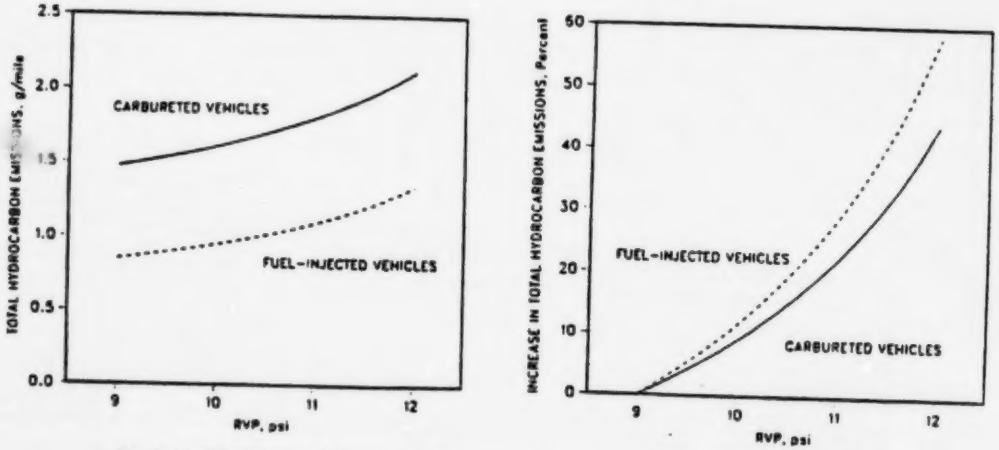
The study by Stebar, et al[58] has shown that evaporative emissions increase significantly as the gasoline RVP increases from 9 psi to 12 psi. As illustrated in Figures 4.4 and 4.5, the hydrocarbon emission through evaporation is dominated by diurnal loss in comparison to hot soak loss. The evaporative emissions appear to be higher for carbureted vehicles than for those with fuel injection system. However, the relative increase in the emission, due to the change in fuel volatility studied, tend to be much greater for fuel-injected vehicles (x 3.5) than for carbureted cars (x 1.9) as shown in Figure 4.4.

Similar observations have also been reported by other investigators[51, 66]. It appears, however, that such increases in evaporative emissions are vehicle-specific, particularly its make, model year, age and the state of its emission control devices.

The effects of fuel volatility on the exhaust emissions are reportedly not so pronounced as on evaporative emissions[51 54, 58]. As shown in Table 4.3, by increasing the gasoline RVP from 9 psi to 12 psi the exhaust emission of THC increased by 14% - 19%, of CO increased by 17% - 20%, and that of NO_x showed no significant increase[58]. It appears from the table that while the THC emission increased more from fuel-injected vehicles than from the carbureted type, the emission of CO increased more with the latter types.



Gasoline RVP Effects on Diurnal and Hot Soak Evaporative Emissions



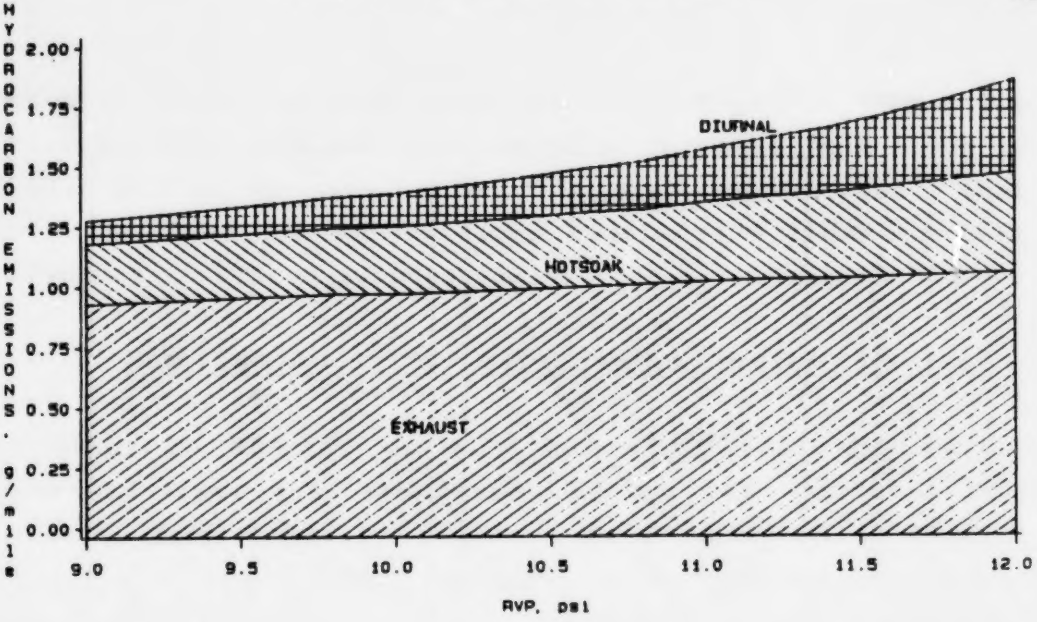
Gasoline RVP Effects on Total Vehicle Hydrocarbon Emissions

Relative Increase in Total Hydrocarbon Emissions with Increased Gasoline RVP

FIGURE 4.4: Effects of Gasoline RVP on Hydrocarbon Emissions

Source: 58

CARBURETED VEHICLES



FUEL-INJECTED VEHICLES

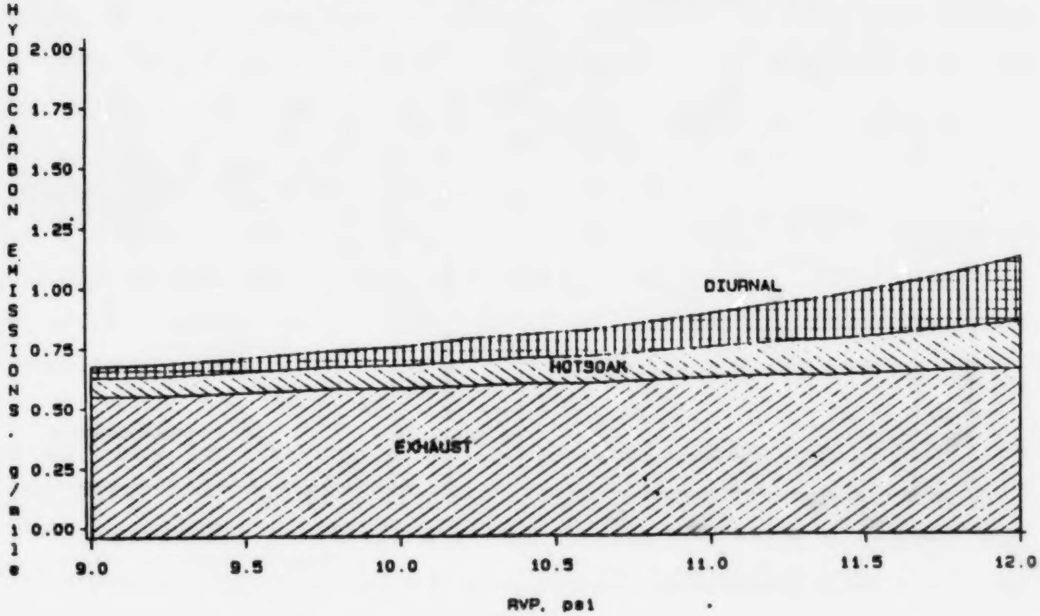


FIGURE 4.5: Contribution of Vehicular Emission Sources to Hydrocarbon Emissions as a Function of Gasoline RVP

(Excerpted from Ref. 58)

TABLE 4.3

Effects of Increasing Gasoline RVP to 12 psi on Vehicle Exhaust Emissions

Contaminant	Exhaust Emissions Increase	
	% Relative to 9 psi RVP	
	Carbureted Vehicles	Fuel Injected Vehicles
THC	14	19
CO	20	17
NOx	2	1

Source: 58

Stebar, et al[58] reported no adverse impact of summer gasoline volatility reduction to 9.0 RVP on vehicle driveability, cold start and warm-up even for the recent model vehicles. They also estimated that the cost-effectiveness of volatility reduction would be competitive with several other measures for hydrocarbon emission control in their investigation area.

4.2.4.4 Potential Impact of Gasoline Volatility Reduction on Hydrocarbon Emission

Any reduction in hydrocarbon emission from this measure would be entirely area-specific, and its cost-effectiveness would also vary from one area to another. However, Stebar, et al[58] have estimated the impact of reducing the average summer gasoline RVP from 11.5 psi to 9.0 psi on the 1987 THC emission inventories in Detroit and New York. They have also made similar estimation for the Dallas area, but only for the reduction of average RVP from 10.0 psi to 9.0 psi. It is reported that the THC emission inventories could be reduced by 5.3%, 7.2% and 3.1% in Detroit, New York and Dallas respectively by such a measure, and it would be cost-effective relative to other control measures.

4.2.5 Currently Available Emission Control Technology

Because of the introduction of stringent emission and fuel economy standards[52, 55] in 1981 in the U.S.A., and in 1979 in the State of California, the post-1980 control technology for the light duty vehicles merits a separate discussion. Similar control technology is expected to be prevalent in the Canadian vehicle fleet once the new emission standards[59] become effective in September 1987, which will be dealt with in a later section.

As the existing technologies for the control of crankcase blow-by and evaporative emissions appear to be reasonably effective, it is unlikely that these would be replaced in the near future. To meet the new exhaust emission standards, and specifically that applicable to NO_x, the vehicle manufacturers have adopted a control technology based on three interdependent systems[55, 57, 70], as shown schematically in Figure 4.6. The systems are: 1) the fuel delivery system, 2) the engine control system, and 3) the exhaust treatment system. The fuel delivery system is either carbureted or fuel injected. The carburetors can be designed to incorporate sealed idle fuel/air mixture, speed, and choke valve adjustment. Fuel injection system can be a throttle body or multi-point, which may be controlled electronically or mechanically for injection timing and fuel pressure to adjust the air/fuel ratio.

The engine control systems are classified as either the conventional open-loop or a closed loop system. In the latter class of vehicles an on-board microprocessor receives inputs on engine operating parameters through various sensors, processes these inputs, and then feeds back a corrective signal to the fuel delivery system on a continuous basis to close the loop. The conventional open-loop vehicles are not equipped with any such feedback mechanisms.

The exhaust treatment systems available are of two catalytic types - the conventional oxidation and three-way catalytic systems. It has been reported[70] that some small vehicles, particularly with unique engine type, can meet the new emission standards by using an oxidation catalyst, exhaust gas recirculation, and air pump or pulse air combination, instead of a reduction catalyst or the three-way catalyst system. Most manufacturers are, however, relying on the

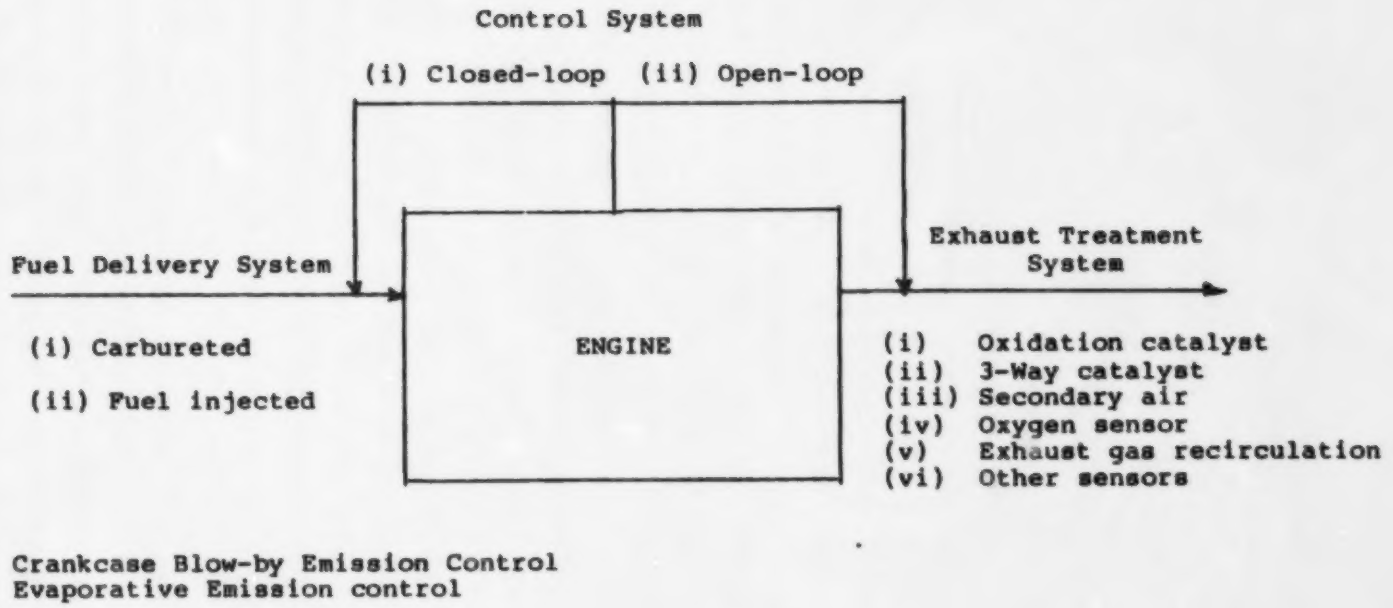

Control System
(i) Closed-loop (ii) Open-loop
Fuel Delivery System
(i) Carbureted
(ii) Fuel injected
ENGINE
Exhaust Treatment System
(i) Oxidation catalyst
(ii) 3-Way catalyst
(iii) Secondary air
(iv) Oxygen sensor
(v) Exhaust gas recirculation
(vi) Other sensors
Crankcase Blow-by Emission Control
Evaporative Emission control

FIGURE 4.6: Schematics of New Emission Control Systems for Light Duty Gasoline Vehicles

closed-loop three-way catalyst system which can be further sub-divided into two types - dual bed and single bed[54, 57, 70]. Dual bed types are those equipped with a three-way catalyst bed followed by an oxidation catalyst with a provision for a secondary air supply to the latter catalyst bed. In the single bed type only a three-way catalytic converter is employed. During any significant malfunctioning, the vehicles equipped with a dual bed systems are designed to operate in a failure mode. Under such circumstances, the secondary air is usually diverted to either the air cleaner or to the atmosphere instead of supplying air to the oxidation catalyst. This measure is reportedly taken to protect the oxidation catalyst from overheating. Some manufacturers have also designed their vehicles to operate on a fuel-rich mode during the failure of the closed-loop systems.

Considering the recent trend in the control technology mix of the vehicle fleet in the U.S.A., it is most likely that the closed-loop system with a three-way catalytic converter will eventually become the prevalent control technology in this country too. However, even then the urban vehicle fleet here is expected to have a mixed emission control technology[71], as listed in Table 4.4; because many of these items will continue to be installed on newer vehicles.

4.3 Emission Standards and Compliance Tests for New Vehicles

To regulate the emissions from motor vehicles, the federal government first enacted standards, shown in Table 4.3, for new light duty gasoline powered vehicles in 1971 which still remain in effect[72]. Recently more stringent standards, also shown in the above table, than the current ones have been promulagated to be effective on September 1, 1987 for 1988

TABLE 4.4

List of Emission Control Systems and Accessories in the Current Fleet of Vehicles

Emission Control Parts:

(Emission Control Parts are those which are included in the car specifically for the purpose of controlling emissions).

1) Exhaust Gas Recirculation System

   - EGR valve
   - EGR spacer plate
   - Thermal vacuum switch
   - EGR backpressure transducer

2) Evaporative Emissions Control System

   - Evaporative Canister

3) Crankcase Emissions Control System

   - PCV valve

4) Early Fuel Evaporative (EFE)/Heat Riser Systems

   - EFE valve
   - Thermal vacuum switch
   - Heat riser valve

5) Air Injection System

   - Air pump
   - Reed valve
   - Anti-backfire (diverter) valve

6) Catalytic Converter System

   - Catalytic converter and exhaust system up to the converter
   - Oxygen sensor
   - Computer command control modules

7) Spark Advance Control System

   - Vacuum advance unit
   - Electronic spark controls
   - Transmission controlled spark system

8) Hoses, gaskets, brackets, clamps and other accessories used in the above systems

Emission Related Parts:

Emissions Related Parts are those parts which have a primary purpose other than for emission control but which nonetheless have a significant impact on emissions)

1) Carburetion System

   - carburetor
   - choke

2) Fuel Injection System

   - fuel injectors
   - fuel distributor

3) Air Induction System

   - thermostatically-controlled air cleaner
   - air box

4) Ignition System

   - distributor
   - injection wires and coil
   - electronic controls
   - spark plugs

5) Hoses, clamps, brackets, gaskets and other accessories used in the above systems

and subsequent model year (MY) vehicles[59], as shown in Table 4.5. There are already regulations prohibiting crankcase blow-by emissions, and restricting the fuel tank filler inlet size for vehicles equipped with emission control device which may be impaired by the use of leaded gasoline[73].

In British Columbia, under the Motor Vehicle Act[74], new vehicles are required to meet exhaust emission standards for THC and CO only, and evaporative emission standard for THC. The Act also prohibits the emissions of crankcase blow-by. However, as shown in Table 4.6, the emission standards for the above contaminants are somewhat different from the current federal standards. No new standards for the 1988 and subsequent model year vehicles have yet been enacted in this Province.

Because of the unique geo-political reality of Canada and the resultant "spill-over" of technology from the U.S.A., it is appropriate to discuss briefly the status of the emission standards in that country. The current emission standards for THC and CO in Canada are less stringent than those were effective in the U.S.A. during 1975-1980, but the present Canadian NO_x standard is the same as that was prevalent in the U.S.A. during the above period[55, 57]. The new standards for 1988 and subsequent MY vehicles are the same as those in vogue in the U.S.A. since 1981, except that for CO until 1983, because of a provision for a two-year waiver to a less stringent CO standard[55, 59].

In both countries, these standards are applicable to new vehicles only and intended to be effective during the "useful life" of the vehicles. The "useful life" is defined as 5 years or 80,000 km (50,000 miles) of use, whichever occurs first[55, 73].

TABLE 4.5

Canadian Emission Standards for Light Duty Vehicles

g/km(g/mile)

Contaminants	Effective - Since 1975		Effective - September 1, 1987	
	Passenger Vehicles	Trucks	Passenger Vehicles	Trucks
Hydrocarbons	1.24 (2.00)	1.24 (2.00)	0.25 (0.41)	0.50 (0.80)
Carbon Monoxide	15.50 (25.00)	15.50 (25.00)	2.11 (3.40)	6.21 (10.00)
Nitrogen Oxides[1]	1.92 (3.10)	1.92 (3.10)	0.62 (1.00)	1.43 (2.30)
Particulates[2]	-	-	0.12 (0.20)	0.16 (0.26)
Evaporative Hydrocarbons	24.00*	24.00*	2.00**	2.00**

[1]. As NO_2

[2]. For diesel vehicles

* g/test by Cannister Test (carbon trap)

** g/test by SHED Test (sealed housing evaporative determination)

Source : 59

TABLE 4.6

Existing Exhaust and Evaporative Emission Standards for Light Duty Gasoline Vehicles in British Columbia and Canada

Emissions and Contaminants	Standards	
	B.C. Motor Vehicle Regulations Div. 29 (Aug. 1984)	Canada Motor Vehicle Safety Standards, Schedule V, Sec. 1103 & 1105. (Jan.1979)
Exhaust Emissions:		
THC, g/1.6 km	2.2	2
CO, g/1.6 km	23	25
NO_x, g/1.6 km	-	3.1
Evaporative Emissions:		
THC, g/test (Canister)	6	2

Test procedures appear to be similar in both cases.

4.3.1 Compliance Tests for New Vehicles

In Canada there are no mandatory requirements for testing of new vehicles by the manufacturers. The federal Department of Transport and Environment Canada carry out compliance audit tests of typical new vehicles in accordance with the procedure described in the Motor Vehicle Safety Act (MVSA) regulations[75]. The procedure is similar to the Federal Test Procedure (FTP) of the EPA in the U.S.A.

The exhaust emissions from new vehicles sold in this country are apparently well within the current emission standards, when adjusted to the manufacturers' specifications[75]. Based on the compliance test data from Environment Canada, the average emission rates of new vehicles of the past model years, as shown in Figure 4.7, appear to be approximately 35% to 65% of the applicable standards[77]. It should be noted, however, that the number of tests for each major engine family representing the fleet volume was rather limited. A recent survey[57] has revealed that the presently used control technologies are more than adequate to meet the current emission standards. It has also been reported that approximately 15% of all new vehicles sold during 1984 in the country were equipped with three-way catalytic converter systems capable of meeting even the new standards[76]. This figure is estimated to be about 20% in the year 1988[78].

In the U.S.A. the regulations for compliance with the emission standards are more varied and stringent. Under the Clean Air Act, the EPA has enacted the Federal Motor Vehicle Pollution Control (FMVPC) program which consists of four elements[54], [55]. Three of these elements deal with new vehicles and another concerns "in use" vehicles. The FMVPC regulations for new vehicles include vehicle certification

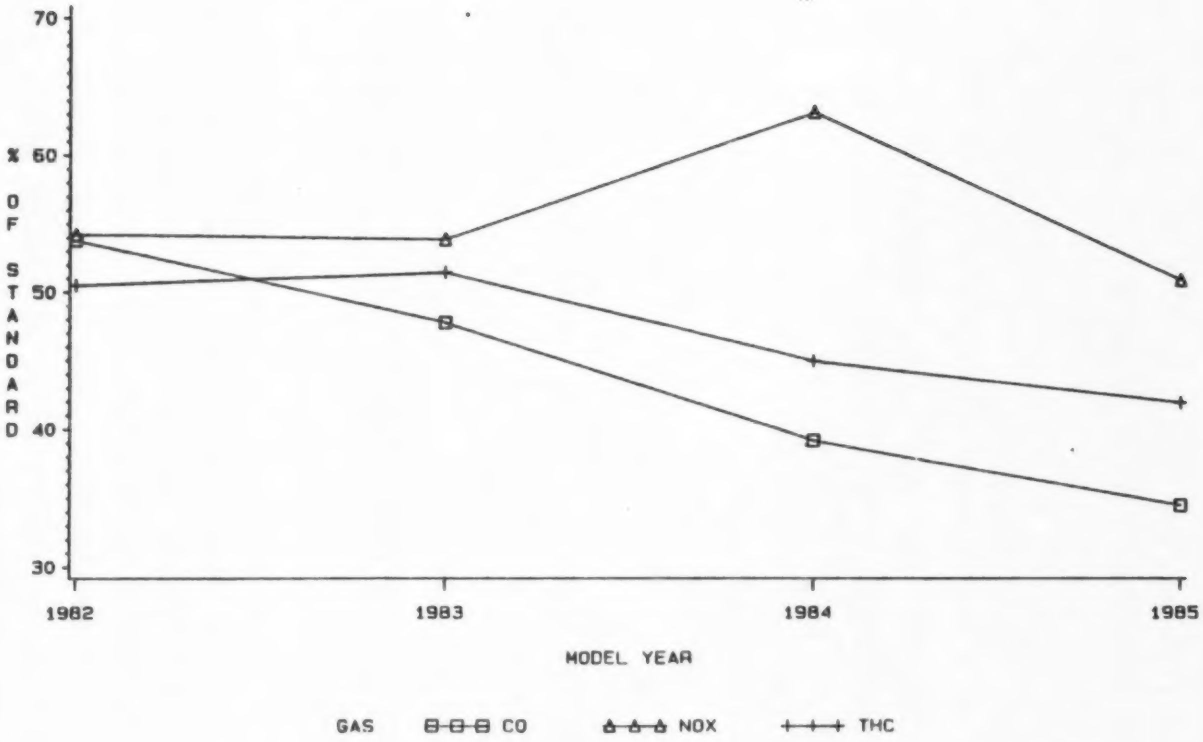


FIGURE 4.7: Average Compliance Test Data For New Light Duty Gasoline Vehicles

Source: 77

program assembly line testing through selective enforcement audit (SEA) program, and manufacturers' warranty and recall program.

The certification program involves testing of prototype vehicles. For each engine family with a particular emission control system produced in a given model year, a vehicle representing that family must demonstrate the ability to comply with the applicable emission standards up to 50,000 miles in order to be certified[70].

In the SEA program, the EPA tests production vehicles in their assembly line state of adjustments, including any other adjustments usually made prior to the vehicle's delivery. The EPA also carries out vehicle surveillance testing, and based on the results, may order a manufacturer to recall a model line, in whole or in part, for repair or replacement of the emission control related devices[55, 79]. The emission tests for all these programs are measured by the FTP. However, it is an expensive, time consuming and complicated method designed to duplicate urban driving in the laboratory.

4.4 In-Use Vehicle Emissions and the Need for Inspection and Maintenance

The emissions from new or "green" vehicles are often unrepresentative of that from similar vehicles after the "break-in" period. Once the new vehicles are on the road, their ability to maintain the emission characteristics often fails within a short period. The primary causes of such emission deterioration are failures of engine and/or emission control components due to:

- maladjustments of engine parameters,
- disablement by physical tampering, and
- disablement by misfueling
- design failures,

The occurrences of increased emissions due to the first three causes are mostly avoidable, as these result from certain actions or inactions of the vehicle owner or maintenance personnel. Numerous tests on typical used vehicles, mostly of pre-1981 MY in the U.S.A., have shown that nearly 50% of the 1-year old and about 60-70% of the 5-year old vehicles on the road exceed the certification standards for THC and CO[52,70]. Similar deterioration in NO_x emission from similar vehicles has also been reported by other investigators[55,56]. Any design failures are usually remedied by the manufacturers, particularly in the cases of new vehicles under warranty.

The prevalence of maladjustment, tampering and misfueling incidences within an urban fleet of in-use vehicles is outlined in the following sections. It should be noted, however, that because of the interrelated nature of some engine and emission control systems, similar emission deterioration often occurs as a result of more than one of the above actions. For example, misfueling of the vehicle is frequently carried out by tampering with the fuel inlet. Thus, misfueling by this method can be considered as an act of tampering too. Therefore, it is important to avoid the possibility of any double-counting when analyzing any survey results to establish quantitative relationship between such actions and increased emissions. In the following discussion, an attempt has been made to identify the overlapping categories wherever possible.

4.4.1 Maladjustments

In order to meet the emission standards, the manufacturers preset various engine parameters at the factory, and recommend a maintenance schedule for the engine components as well as emission control devices. No readjustments to these systems should be necessary for at least the useful life of a vehicle if it is maintained accordingly. However, some of these engine parameters can be adjusted on in-use vehicles to other settings which could result in emissions far exceeding the standards. Investigations[80] by the EPA, under the Restorative Maintenance Program, have indicated that the most commonly maladjusted engine parameters are idle fuel/air mixture, idle speed, choke valve action, and initial spark timing.

There are several possible reasons for improper adjustments of engine parameters on in-use vehicles. Some vehicles may have been delivered to their owners without proper adjustments. It is also likely that some maladjustments may occur spontaneously during use without affecting the driveability of the vehicle, and hence not be corrected because of inadequate maintenance. Because of lack of knowledge or of proper test equipment, many mechanics probably deviate from the manufacturer's specifications while the engine components are serviced. The vehicle owners and mechanics may also make incorrect adjustments deliberately in an attempt to rectify complaints about cold starting, quality of idle or acceleration.

To discourage maladjustments and thus improve in-use performance, the EPA introduced Parameter Adjustment regulations[80] for 1981 and later model year vehicles to have certain adjustable parameter settings sealed or inaccessible. Initially such parameters included idle air/fuel mixture, idle speed, choke valve action and spark timing; however, the idle speed has since been exempted from the list[70]. In Canada there are no such regulations to deter adjustments of these engine parameters; but many vehicles sold here have sealed carburetors[76].

The above regulations of EPA are also applicable to the vehicles equipped with fuel injection systems[80]. With the introduction of catalytic converters, various sensors and microprocessor-based control systems, the need for manual adjustments may be reduced. However, any maladjustments of any of the engine parameter settings could significantly increase the exhaust emissions[52, 55, 70, 76].

The maladjustment of carburetors can also be regarded as an act of tampering. Thus there is an overlap of tampering and carburetor maladjustments. In 1984 tampering survey in the U.S.A., EPA observed that 71% of the tampered vehicles with conventional carburetors also had missing limiter caps or sealed plugs. Several inspections[76] of 1982 and 1983 model year vehicles in Canada have shown that on a national basis an average of 23% of these vehicles with sealed carburetors had been maladjusted. The rate of such practice varied from 8% to 30%, depending on the urban area surveyed. The maladjustment rate of older model vehicles appears to be much higher in the U.S.A. according to Elston[55], who has reported the rate to be 66% for 1975 and 1976 model year vehicles on a national basis and it ranged from 30% to 60% for 1977 model year cars in four cities. It should be noted that these vehicles did not have mandatory sealed carburetors. Similar high rate, about 67% of maladjusted carburetors in 1977 and 1979 model year vehicles in Canada has also been reported by Environment Canada[76].

Another common telltale sign of engine malfunctioning is ignition or misfire problem in a vehicle. The signs are visible and/or audible, and it is associated with excessive THC emission resulting from incomplete combustion of the fuel. Adjustments of the fuel/air and spark systems to the manufacturer's specifications in older model vehicles may be the only repair necessary in most cases to correct the problem. However, such problems in vehicles of recent model years with electronically controlled fuel injection and ignition systems may require component replacement. It should also be noted that these problems increase with the vehicle age.

4.4.2 Tampering

In this discussion tampering will refer to any disablement of any element of the emission control system whether it is done deliberately, inadvertently or through negligence. The enlargement of the fuel inlet restrictor is also included in the tampering category, although it is one of the indicators of misfueling which is discussed later. This overlap is of considerable significance when excess emissions due to both tampering and misfueling are estimated, and due caution should be exercised. The most common emission control components or systems which have been observed to be tampered are: positive crankcase ventilation system (PCV), evaporative system, exhaust gas recirculation system (EGR), air inlet system, fuel inlet system, and catalytic converter[76, 81, 82]. The electronic control module, various sensors, and thermal air cleaner have also been cited as the subject of tampering in new technology vehicles[56, 82-85].

4.4.2.1 Characteristics of Tampering

During the last few years Environment Canada, in co-operation with respective provincial agencies, set up several inspection clinics for in-use vehicles in various cities[76, 86]. Since the participation in these clinics were voluntary, many deliberately tampered vehicles would not have been presented for inspection and therefore actual tampering rates could easily be greater than that reported. Apart from the sealed carburetor tampering mentioned earlier, the disablement of EGR system was inspected in eight cities. The major observations were that the tampering and malfunction of EGR system varied from one location to another, and the rate ranged from 19% to 32% with an average of 26%. The incidence of EGR disablement appears to increase with vehicle age, as observed in Quebec City and Vancouver surveys. In Vancouver, the rate of such tampering varied from 0% for the latest model (1982) to 64% for the oldest model (1973) vehicle surveyed, with an average of 28% for a fleet of 311 vehicles[86].

The tampering of air inlet system has not been observed to be widespread, although some instances were noted in Quebec City and Winnipeg[76]. Only one limited inspection of catalytic converter tampering was carried out in 1983 in Quebec City, and it was found that 20% of the vehicles had the system removed[76].

In the U.S.A. systematic nationwide tampering surveys have been carried out by EPA since 1978[81]. For the purpose of comparisons and identification of trends, consistent inspection procedures have been used throughout these surveys. The surveyed vehicles consisted of both automobiles and light duty trucks, and the locations included areas with an I/M program, an I/M and anti-tampering (ATP) program, and without any emission or anti-tampering inspection.

The trends in the tampering rates of major emission control systems in the U.S.A. are shown in Figure 4.8. However, as these data have not been weighted to compensate for I/M program implementation, the rates shown in Figure 4.8 probably underestimate the actual rates on a nationwide basis[81]. The prevalent tampering rates for the year 1984 are shown in Table 4.7, and it appears that nearly one in five in-use vehicles have at least one emission control device disablement in the U.S.A. It should be noted that in these surveys a vehicle was classified as "tampered" if at least one control device was removed or rendered inoperative. Besides this category, EPA also classified the inspected vehicles into "malfunctioning", "arguably tampered" and "okay" categories[81]. While malfunctioning vehicles did have emission control devices inoperative or improperly operating, these were not considered to be due to any action of the vehicle owner or its mechanic. The classification of arguably tampered appears to be somewhat subjective, as these vehicles were regarded as possibly tampered but not definitely. The vehicles with all emission control equipment present and apparently in proper working condition were classified as okay. In the 1984 survey it was observed that the overall averages for the above categories were: tampered - 22%, malfunctioning - 4%, arguably tampered - 29%, and okay - 46%.

For the purpose of this discussion, the observations by EPA on the incidences of definite tampering of emission control systems/components in automobiles are considered only. It should be noted, however, that in addition to the major

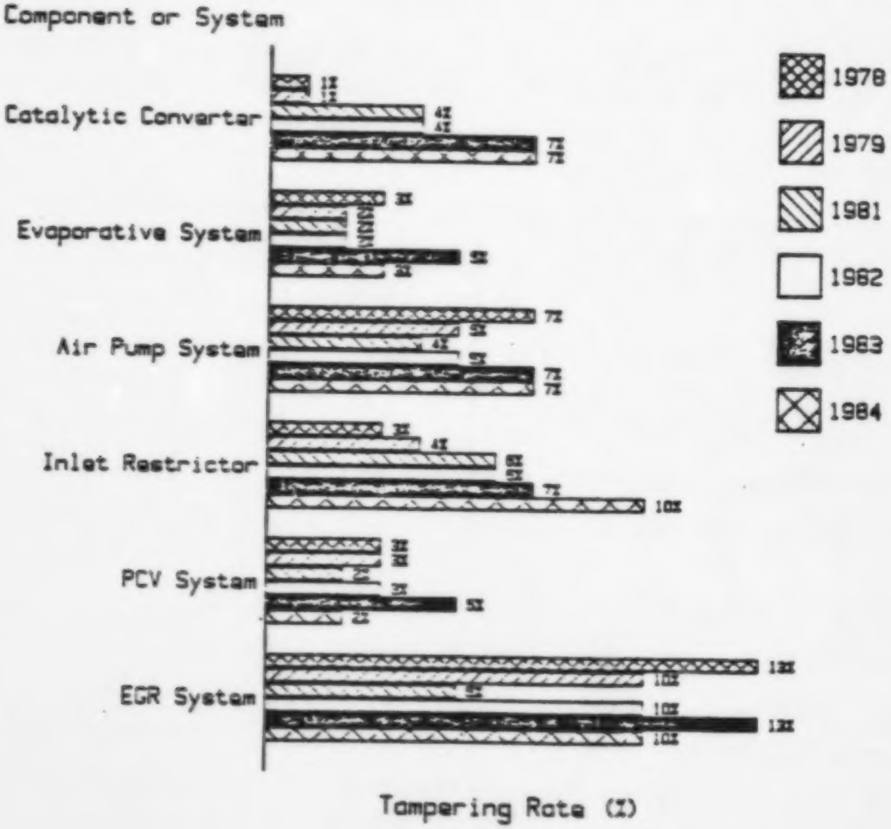


FIGURE 4.8: Component-Specific Tampering Rates: 1978 - 1984 National Average in the U.S.A.

Source: 81

TABLE 4.7

Prevalence of Tampering Rates of Critical Emission Control Components by Vehicle Type in the U.S.A.

(1984 Survey)

Emmision Control Component/System	Tampering Rate, %		
	LDGT	LDGV	Overall
Catalytic Converter	14	5	7
Fuel Inlet Restrictor	14	9	10
AIR System	12	7	7
PCV System	3	2	2
Evaporative Control System	5	2	3
EGR System	10	10	10
Overall	27	21	22

LDGT - Light Duty Gasoline Truck
LDGV - Light Duty Gasoline Vehicles

Source: 81

emission control devices listed in Table 4.7, the following components have also been observed by EPA to be the prevalent targets of tampering or suspected tampering: aspirated air system, thermal air intake, spark retard system, idle mixture limiter cap, and idle stop solenoid. The 1984 survey results indicate that in the U.S.A., despite regulations, a large portion (71%) of the tampered vehicles with conventional carburetors also had missing sealed plugs or limiter caps.

The major observations from the tampering surveys[81] in the U.S.A. can be summarized as follows. The tampering rate for each emission control component on automobiles tends to be the same or lower than on light duty trucks. It has been observed in all surveys that the overall tampering rate is higher among domestic vehicles than those manufactured in Europe and Japan. Similar observations were made in 1981 field study in Vancouver[86] with regard to EGR tampering.

Since 1978 each survey has shown that vehicle tampering rates increase fairly linearly with vehicle age. In a 1984 survey, as illustrated in Figure 4.9, the overall tampering rate increased from 1% for the first year vehicles to about 46% among the ten-year old vehicles. More detailed analysis of survey results has indicated a general pattern that the increase in tampering rate with vehicle age appears to lessen once the vehicles of a particular MY are five years old or more, with the rate of tampering levelling off at higher levels in older model years. However, as the proportion of older vehicles in the survey sample had increased during each successive survey from 1978 to 1984, the overall tampering rate showed gradual increase with the vehicle age.

From Figure 4.9 it appears that the catalytic converter tampering rate is also similarly related to vehicle age and model year. It has been observed in all surveys that catalytic converters are as susceptible to tampering on new

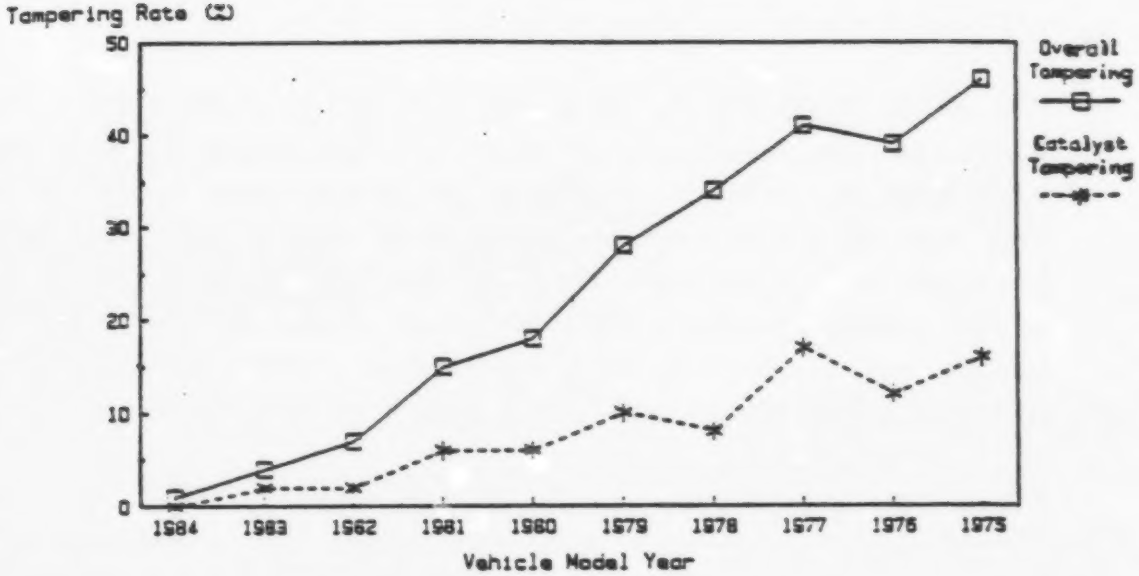


FIGURE 4.9: Overall and Catalyst Tampering Rates in the U.S.A. by Vehicle Model Year - 1984 Survey

Source: 81

vehicles as on older ones at a particular vehicle age. Such tampering rate remains negligible for the first two to three years of a new vehicle, and then appears to increase in subsequent years.

Tampering rates have been found to be higher in areas without any emission I/M program than in locations with an I/M program, as shown in Table 4.8. It is also evident from Table 4.8 that the tampering rates in I/M only areas are higher than in I/M and ATP areas. Similar observations were made in previous surveys. The effectiveness of an anti-tampering program on the tampering rate is illustrated in Figures 4.10 and 4.11. While New Jersey's I/M program is the first one to start in the U.S.A., it does not have any anti-tampering inspection. On the other hand, the Portland, Oregon program, which started with emission testing in July 1975, has included visual inspection of emission control systems since 1977. As shown in the above figures, the tampering rates in the Portland area are significantly lower than the corresponding rates in New Jersey. A survey[87] conducted by the Motor Vehicle Manufacturers Association (MVMA) in the U.S.A. in 1985 has found basic agreement with the latest EPA observations mentioned above.

An analysis of recent I/M program data by the Oregon Department of Environmental Quality has shown that the tampering rates in the Portland area are significantly lower than that observed in national surveys[82]. The overall tampering rate among 1975-1980 MY vehicles in Portland in 1983 was 8% compared to the corresponding national observation of 26%. The rates observed in 1984 and 1985 in Portland for the same group of vehicles were 6% and 7% respectively. Amongst the post-1981 MY vehicles the overall tampering rate varied from 1.5% to 2.5% during the 1983-1985 period. It should be noted, however, that the Portland I/M program is considered as one with the least number of deficiencies, as discussed in a later section.

TABLE 4.8

Tampering Prevalence in non-I/M and I/M Areas in the U.S.A.

Survey Year	Tampering Rate, %			
	non-I/M	I/M-only	I/M + ATP	Overall
1978	19	NS	NS	19
1979	20	13	NS	18
1981*	14	NS	NS	14
1982	19	15	10	17
1983	29	24	16	26
1984	31	17	11	22

NS = None Surveyed

*1981 survey was of limited scope, covering only two sites and 399 vehicles

Source: 81

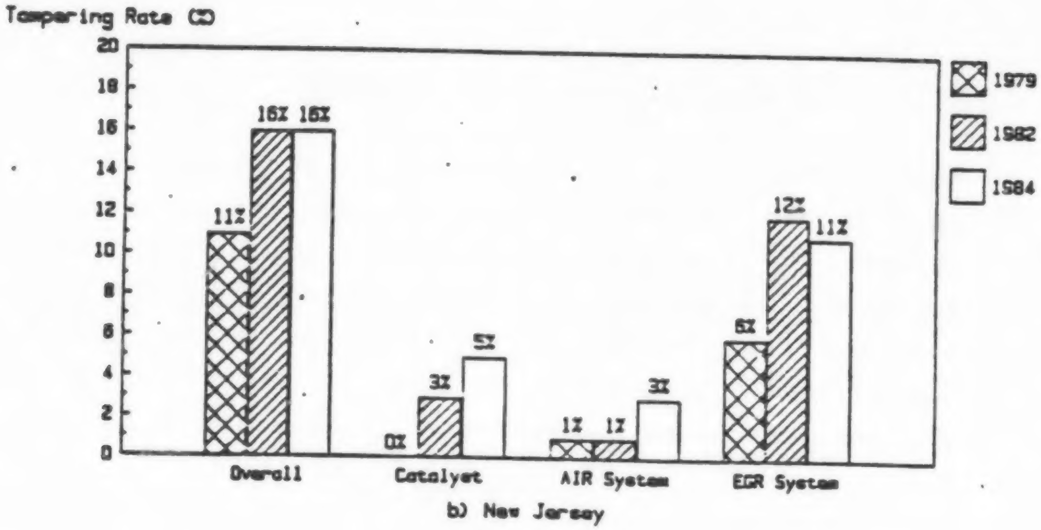


FIGURE 4.10: Tampering Rates in New Jersey I/M Program Area

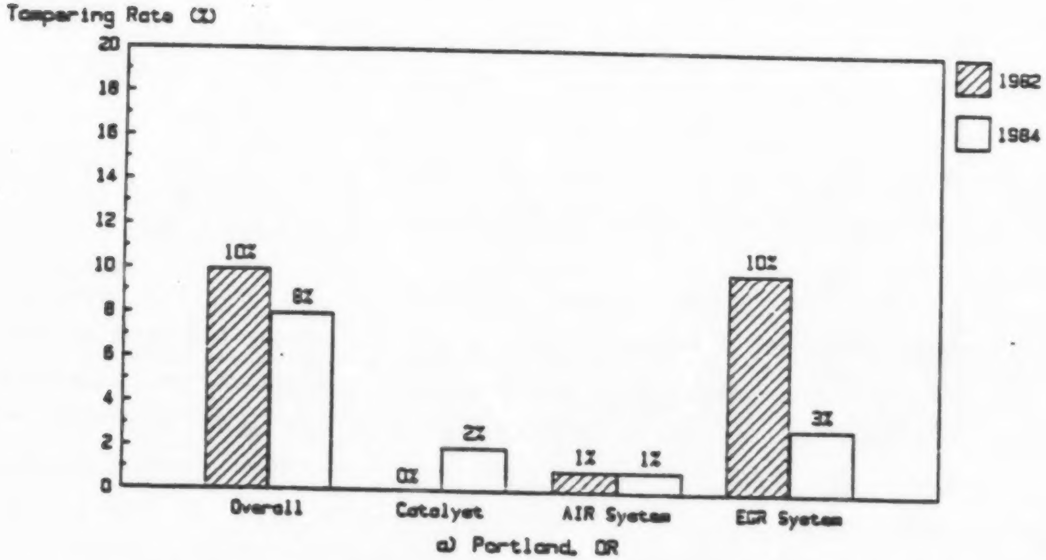


FIGURE 4.11: Tampering Rates in Portland, Oregon I/M Program Area

Source: 81

4.4.2.2 Type and Frequency of Repairs

Another indication of the prevalence of possible tampering in an area can be obtained from the information on the type of repairs and the frequency of each repair performed on the vehicles. In the Portland, Oregon study[83] by EPA it has been observed that carburetor adjustments are by far the most common repair performed, as shown in Table 4.9, on pre-1981 MY vehicles to pass the retest in the I/M program. Other frequent repairs needed on these 1972-1974 MY and 1975-1977 MY vehicles are mostly related to various engine parameters.

Similar investigations[84], [85] by EPA on post-1980 MY vehicles in Washington, D.C. and Maryland I/M program areas have provided information on vehicles equipped with new emission control systems. Of the 1980 and 1981 MY vehicles tested in Washington, D.C. area many had disabled mixture plugs, 32% had to be "tuned-up", 15% had major carburetor work done, and 7% of the closed-loop vehicles had a closed-loop fault[73]. Many minor conventional repairs were also performed on most vehicles to pass the retest.

In the Maryland investigation[85], out of 100 vehicles of 1981-1984 MY tested it was observed that 40% had shown signs of either tampering or improper maintenance. Although a variety of repairs were necessary for the 100 vehicles to pass the I/M retest, about 44% of them needed some minor repairs only. The frequency of each type of repair required for these vehicles is summarized in Table 4.10. It is evident that some adjustment to the carburetor was the most frequently performed repair on the carbureted vehicles, both open- and closed-loop. The most frequently repaired system in the fuel injected vehicles was the 3-way electronics or the closed-loop systems, in particular the oxygen sensor. The frequency of maintenance required on the 3-way

TABLE 4.9

Typical Repairs Performed on Vehicles Failing the Portland, Oregon I/M Program

Types of Repair Performed	Model Year Vehicles	
	1972-1974	1975-1977
Spark Plugs	35.8%	25.4%
Spark Plug Wires	14.7%	11.9%
Points and Condensor	31.6%	5.6%
Distributor Cap and Rotor	17.9%	6.3%
Spark Timing Control Devices	13.7%	10.3%
Carburetor (Idle Mixture Adjustment)	87.4%	89.3%
Choke	48.4%	21.8%
Intake System	5.3%	4.0%
Air Filter	31.6%	31.0%
Engine Oil	21.1%	15.1%
Idle Speed	48.4%	73.4%
Timing	49.5%	46.0%
Dwell	41.1%	26.6%
Air Injection System	5.3%	3.2%
EGR System	6.3%	4.8%
PCV System	6.3%	7.5%
Valves	7.4%	0.8%
Total Number of Vehicles	95	252

Source: 83

TABLE 4.10

Frequency (%) of Repairs by Emission Control System in Maryland I/M Program

System Repaired	Open-Loop Carbureted	Closed Loop	
		Carbureted	Fuel Injected
Induction System:			
Air Filter	9.4	10.2	5.3
TAC	3.1	4.1	-
Fresh Air Tube	3.1	2.0	-
TOTAL:	15.6	16.3	5.3
Carburetor Replacement	3.1	2.0	NA
Fuel Metering System:			
Set Idle CO	46.9	51.0	10.5
Set Curb Idle	62.5	28.6	10.5
Mix. Solenoid	-	6.1	-
Clean/Replace Choke	-	8.2	NA
TOTAL:	90.6	67.3	15.8
Ignition System:			
Distributor	6.2	6.1	-
Plug Wires	6.2	6.1	10.5
Timing Module	3.1	-	-
TOTAL:	12.5	12.2	10.5
Reset Timing:			
Advance[1]	3.1	8.2	-
Retard[2]	12.5	6.1	-
TOTAL:	15.6	14.3	-
EGR	-	6.2	8.2
Supplementary AIR	25.0	24.5	10.5
PCV System:			
PCV Valve	-	4.1	-
PCV Hoses	-	4.1	-
TOTAL:	-	6.1	-
3-Way Electronics:			
ECM	NA	18.4	-
PROM	NA	6.1	-
O_2 Sensor	NA	24.5	63.2
Misc. (TPS)	NA	8.2	5.3
TOTAL	NA	36.7	68.4
Catalyst Replacement	-	6.1	-
Sample Size:	32	49	19

[1] - The repair was to advance the timing to spec.
[2] - The repair was to retard the timing to spec.

TAC - Thermal Air Cleaner
EGR - Exhaust Gas Recirculation
PCV - Positive Crankcase Ventilation
ECM - Electronic Control Module
PROM- Program Read Only Memory
TPS - Throttle Position Sensor

Source: 85

electronics, as well as on the oxygen sensor, systems of the closed-loop carbureted vehicles was also significant.

The above investigation[85] also revealed that, irrespective of the model year, approximately 40% of the closed-loop vehicles required a sensor, usually oxygen, replacement, as shown in Table 4.11. It appears that the frequency of repair to the Electronic Control Module (ECM) and/or the Program Read Only Memory (PROM) dropped from about 19% of 1981-1982 MY vehicles. The investigation was unable to provide a definitive reason for the sudden decline in the ECM and PROM maintenance requirement.

4.4.3 Misfueling

The term misfueling is usually referred to the practice of using leaded gasoline in a vehicle designed to use unleaded gasoline. These vehicles are usually equipped with a catalytic converter, and the lead in the fuel poisons the catalyst. The poisoning or deactivation of the catalyst by a prolonged misfueling could eventually make it useless as a device to control emissions through the vehicle tailpipe.

Misfueling of vehicles is difficult to determine as there are more than one indicator of such practice. One of the indicators is a tampered fuel filler inlet restrictor, which has already been discussed in the previous section. Other indicators are: nozzle switching at service stations, slow filling, use of a funnel or adapter, a positive test for lead deposits in the vehicle tailpipe, and the presence of leaded fuel in the vehicle tank. Because of the variety of indicators to measure misfueling, one must be careful in comparing misfueling rates of different surveys as well as in determining the trend in a particular survey area if the indicators vary from one period to another.

TABLE 4.11

Frequency (%) of Repairs to Electronic System and Sensors in Closed-Loop Vehicles by Model Year

Device Replaced	Model Year			
	1981	1982	1983	1984
ECM or PROM	20%	18%	0%	0%
Sensor (O_2 or TPS)	40%	35%	42%	44%
Sample Size:	30	17	12	9

ECM - Electronic Control Module
PROM - Program Read Only Memory
TPS - Throttle Position Sensor

Source: 85

In the Lower Mainland area surveys of nozzle switching at service stations since 1983 have been carried out to provide an indication of misfueling rate. The results indicate that such practice has declined dramatically from 68% in 1983 to 7% and about 4% in 1984 and 1985 respectively[88].

Another comprehensive survey[89] was undertaken in various cities in the country in 1985 to determine the incidences of misfueling in the country. The findings indicate that in the Vancouver area misfueling by nozzle substitution was 2%, compared to 4% in Ottawa and 8% in both Toronto and Montreal. However, based on the vehicular observation, the incidence of misfueling by various means, including through tampered fuel inlet restrictor, was estimated to be 13%, amongst the vehicles designated for unleaded gasoline, in Vancouver. The corresponding figures for Ottawa, Toronto and Montreal were estimated to be 9%, 12% and 9% respectively. As a percentage of total vehicles the misfuelers were 9% in Vancouver, as compared to 7%, 9% and 7% in Ottawa, Toronto and Montreal respectively.

The above mentioned survey also revealed that on a national basis most of the misfueling (91%) was carried out through the tampered fuel inlet restrictor, while the remainder was done by nozzle switching (4%), slow filling (3%), and by funnel or adapter (<1%).

In the U.S.A., EPA has been carrying out misfueling surveys since 1978; however, it is only since 1981 the surveys have used a combination of three indicators to determine misfueling rate more accurately[81]. These indicators are: tampered fuel inlet restrictor, lead concentration of more than 0.05 grams/US gallon in the gasoline in the vehicle tank, and a positive Plumbtesmo test for lead deposits in the tailpipe. The misfueling rate is estimated on the basis of at least one positive indication as a reasonable minimum, as false positive indications are considered to be very rare for the above measures.

It has been reported[81] that based on the above criteria, the misfueling rate among vehicles designed for unleaded fuel in 1984 ranged from 7% to 25% with an average of 14% for all sites. The average rates for 1981, 1982 and 1983 were estimated at 16%, 11% and 14% respectively. The results from these surveys indicate that, in general, areas without an I/M program has the highest rate of misfueling, followed by I/M-only and I/M and ATP areas. It has also been observed that, while the overall rate has not changed appreciably, the misfueling rate in non-I/M areas has been increasing steadily. Misfueling by tampering the fuel inlet restrictor appears to show an increasing trend.

The surveys in the U.S.A. also indicate that the misfueling rates for light duty trucks are considerably higher than for passenger vehicles. The misfueling rate appears to increase with vehicle age, and reach a maximum of 20% to 30% with 6- or 7- year old vehicles.

As misfueling and removal of catalytic converters are somewhat related in terms of motivation, it seems reasonable to expect some overlap between the rates of these two actions. An analysis by EPA of their tampering and misfueling survey results of 1984 indicated that only about one-third of the misfueled vehicles had their catalytic converter removed, and over two-thirds of the misfueled vehicles still had their catalytic converters.

It should be emphasized, however, that there are certain limitations of various indicators of misfueling used in these surveys. For example, a vehicle misfueled intermittently by means other than tampered fuel inlet restrictor may not respond to any of the tests for the presence of lead in the tailpipe or fuel tank. Conversely, a vehicle misfueled accidentally at the service station may be surveyed and considered as a misfueler.

4.4.4 Design Failures

As the number of new vehicles equipped with sophisticated on-board computer and various sensors is increasing every year in an urban fleet, genuine concerns have been expressed about the impact of design failures on the emission characteristics[52, 55, 56, 70, 76]. If, somehow, any one or a combination of these components malfunction, the manufacturers have designed different failure mode operations which may have significant impact on emission characteristics without affecting the driveability of the vehicle.

Any failures occurring in the open-loop controlled oxidation catalyst vehicles are reported to be similar to those experienced with maladjusted carburetors[55, 70]. The resulting excess emissions due to such failures are expected to be of similar magnitude as that from carburetor maladjustment discussed earlier.

The closed-loop vehicles are mostly designed to operate in a "fuel-rich" mode when there is a failure of the closed-loop system components, such as microprocessor, oxygen sensor, and other sensors used to adjust idle speed, spark timing, etc.[55, 70]. Some manufacturers reportedly use "control-rich" and "full-lean" modes of operation during the failure of the closed-loop system[55]. Under such conditions the fuel/air mixture are not as rich in fuel as used in the first category.

Some manufacturers have introduced dash-board warning lights or other systems, which are usually intended to notify the vehicle owner of the need for component repairs, and also to identify any specific malfunction to the mechanic. Any failure of these warning systems may lead to excess emissions due to malfunction of components without the owner or the mechanic being aware of it. Although a functional warning system does not provide any assurance that the vehicles would be repaired, at least such vehicles could be easily identified during an inspection.

It has been reported that about 3% of post-1981 MY vehicles have a microprocessor control failure before they are one year old[52]. In the case of the closed-loop vehicles, any such failure leading to a fuel-rich mode operation could result in extremely high THC and CO emissions[52,55,70,76]. Tests with some vehicles have shown such an operation increases the THC and CO emissions 10 to 15 times above the applicable 1981 emission standards in the U.S.A.[55]. Hence, only a small percentage of the fleet contributes a disproportionately large share of the fleetwide emissions of these contaminants.

5. MOTOR VEHICLE EMISSION INSPECTION AND MAINTENANCE (I/M) PROGRAMS

As discussed in the previous section, the emissions from new motor vehicles are regulated by Federal legislations, and the new model year automobiles do meet the required standards when they are adjusted to the manufacturers' specifications. The concern about pollution, however, emanates from the in-use vehicles which emit excessive amounts of contaminants for a variety of reasons. In an effort to reduce the impacts of emissions from this sector, some types of I/M program for in-use vehicle fleet have been introduced in many urban areas in the world, particularly in the U.S.A. Most of the information on I/M programs, which is readily available in the literature, is related to those in the U.S.A. From the perspectives of British Columbia and Canada, a review of these programs is probably the best method of acquiring some insight into the various aspects of an I/M program design.

5.1 The Status of I/M Programs in Canada

Presently there are no mandatory I/M programs in this country to control emissions from in-use vehicles, except the Drive Save Program[90] in the Province of Ontario, which is discussed later. However, in recent years several I/M related studies[86, 91, 92] have been carried out by Environment Canada in cooperation with some Provincial agencies, primarily for the purpose of generating information. As the control of emissions from in-use vehicles is a Provincial responsibility, the Federal Government does not have any plan to implement I/M programs.

In British Columbia there are legislations under the Motor Vehicle Act prohibiting the sale and operation of new motor vehicles which do not comply with the applicable emission standards for THC and CO, and from which any emission control system or device initially installed is removed or disabled, unless the vehicles comply with the regulations[74]. Any emission from the crankcase of a gasoline-powered motor vehicle is also prohibited.

The Provinces of Nova Scotia, Prince Edward Island have regulations dealing with the use of leaded gasoline in a vehicle equipped with a catalytic converter[93]. In the Province of Quebec, under the Environmental Quality Act there are provisions against the sale or use of light duty motor vehicles of models subsequent to 1985 without a device in good working order to reduce emissions of THC, CO and NO_x[94]. It is also illegal to tamper with any emission control device installed in a vehicle. In the case of a vehicle equipped with a catalytic converter, any modification to the fuel tank inlet and the use of leaded gasoline are also prohibited. The Ministry of Environment of Quebec in cooperation with Environment Canada has recently begun a mechanic's education program and a public information campaign on motor vehicle emission control through a video, "When Something's Missing" and an accompanying brochure[95].

The "Drive Save Program" in Ontario was initiated in 1971 after the enactment of the Environmental Protection Act of 1969, to enforce the provisions of the Act[90]. In 1975 an inspection program to check emission control equipment in motor vehicles was started in the Toronto area and 12-14 municipalities outside Toronto. Approximately 12,000 vehicles a year were examined without any charge to the owners. With the introduction in 1980 of new Regulations[96], emission short tests were also carried out along with the control equipment inspection in one test centre in Toronto and a mobile station. The emission test standards used in Ontario are given in Table 5.1.

Due to the general reduction in staff in recent years, the program is operated at a much reduced level with two inspectors only. At present the test centre in Toronto is used only and about 2,500 - 3,000 vehicles per year are tested. These vehicles are brought into the test centre either voluntarily or by police referral. As for the future plan, the program can only be expanded when resources become available. The emission standards for the short tests may also be revised to accomodate the new federal vehicle emission standards due in September, 1987.

5.2 The Status of I/M Programs in the U.S.A.

In the U.S.A. the Federal Motor Vehicle Emission Control Program (FMVECP) has been operating since 1968. The program can be broadly classified in three categories, namely motor vehicle manufacturer oriented, travel oriented, and in-use vehicle emission oriented. While the manufacturer oriented strategy has been to design and build vehicles for lower emissions, the in-use vehicle emission strategy is complementary to the former. The travel oriented measures are considered to be cost-effective on a short-term basis[43,49].

The I/M program is the most widely applied one under the in-use vehicle emission oriented strategy. In the U.S.A. although EPA decides on the necessity of an I/M program in a

TABLE 5.1

Maximum Emission Standards for Short Tests for Light Duty Motor Vehicles in the Province of Ontario

Engine Displacement (litre)	Model Year	Exhaust Emissions			Visible Emissions of a Contaminant or Contaminants (Seconds in any one-minute period)	
		CO (%)		HC (ppm)		
		Idle Test	Fast Idle Test*	Idle and Fast Idle Test*	Idle Test	Fast Idle Test*
Not more than 2.29	Pre-1969	6.0	5.0	800	5	5
	1969	5.0	3.0	600	5	5
	1970-1971	4.0	2.5	500	5	5
	1972-1974	3.5	2.0	500	5	5
	1975-Newer	2.5	1.5	400	5	5
More than 2.29	Pre-1969	5.0	3.0	600	5	5
	1969	4.0	2.0	500	5	5
	1970-1971	3.0	1.5	400	5	5
	1972-1974	2.5	1.0	400	5	5
	1975-Newer	2.0	1.0	300	5	5

* Fast idle test taken at 2450/2550 rpm.

Source: 96

particular area and requires the respective state agency to implement an approved program, the state is responsible for the program operation. The first I/M program was started in 1974 in the state of New Jersey[55], and three more programs were in place by the end of 1981[97]. However, since the amendments of the Clean Air Act in 1977, many I/M programs have been implemented across the U.S.A.[98]. The status of the various I/M programs in that country as of July 1986 is summerized in Tables 5.2 to 5.4.

An overview of the various features of these I/M programs are provided here only. The characteristics of the major features are discussed in some detail in a later section. Currently, an I/M program of some kind is operating in 31 states and in Washington , D.C. area. A program for the State of New Hampshire is planned for implementation in September, 1987. The program in New Mexico was cancelled in March 1984, but it might restart in a more limited area in the near future[99]. Most of these programs in different states are restricted to certain local metropolitan areas. There are 4 state-wide programs only, compared to a total of 53 area-wide programs.

A summary of the major features of the existing and proposed I/M programs in the U.S.A. is provided in Table 5.5. It appears that some type of emission test, either by itself or in conjunction with other tests, is employed in most of the programs. Anti-tampering and misfueling tests, but no emission test, are carried out, or proposed to be done, in Texas, Louisiana, Oklahoma, and Cincinnati.

TABLE 5.2

Summary of the Status of I/M Programs and Their Major Features in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	PROGRAM									VEHICLES								Inspection Frequency		TEST TYPE																		
EPA Region	State/ Area		Type					Enforcement Methods				Type				Exempted						Safety	Emission				Tampering (Visual & Functional)													
		m/y	CC	CL	CS	DC	SY	R	S	R+S	CM	ALL	LMYN	MY+	MW(lb)	AC	D	MC	OF	A	B		I	TSI	L	OP	AInj	AInt	Cat	CM	EFC	EGR	EVS	FTI	OS	PCV	PHB	RCat	SS
I	Connecticut - Statewide	01/83	X						X					'68	10,000		X	X		X			X				X S.W.	X S.W.	X S.W.			X S.W.	X S.W.	X S.W.		X S.W.			X S.W.
	Massachusetts - Statewide	04/83				X			X				15		8,500		X	X		X		X	X					All applicable devices when seeking waivers.	X MY80+					X					
	New Hampshire - Nashua (Rockingham Hillsborough)	09/87				X?		X					15		8,000		X	X		X		X	X						X MY81+					X MY83+					
	Rhode Island - Statewide	01/79				X			X					'67	8,000		X	X		X		X	X																
II	New Jersey - Statewide	02/74					X		X			X			14,000		X	X		X		X	X						X MY82+					X MY82+				X MY83+	
	New York - New York City Metro Area (Bronx, Kings, Nassau, New York, Queens, Richmond, Rockland, Suffolk Westchester)	01/82				X			X			X			No limit		X	X		X		X	X				X MY84+	X MY84+	X MY84+			X MY84+	X MY84+	X MY84+		X MY84+			

Key to Abbreviations

Program Type

CC - Central contractor
CL - Central local-run
CS - Central state-run
DC - Decentralized
(manual or computer)

Program Enforcement Methods

R - Registration
S - Sticker
R+S - Registration and sticker
CM - Computer matching

Vehicles Type

ALL - All model years
LMYN - Last model year number
MY+ - Model year and later
MW(lb) - Maximum weight (lb)

Vehicles Exempted

AC - Air cooled
D - Diesel
MC - Motorcycles
OF - Other fuels

Test Type

Emission

I - Idle
TSI - Two-speed idle
L - Loaded
OP - Opacity

Tampering (Visual & Functional)

AInj - Air injection
AInt - Air intake
Cat - Catalyst
CM - Computer module
EFC - Electronic fuel injection (Carburetor)
EGR - Exhaust gas recirculation
EVS - Evaporation system
FTI - Fuel tank inlet
OS - Oxygen sensor
PCV - Positive crankcase ventilation
PHB - Plumbtesmo
RCat - Replace catalyst if inlet tampered
SS - Spark system

C.O. - Change of ownership
S.W. - Seeking waiver
F - Failed

TABLE 5.2 (Contd)

Summary of the Status of I/M Programs and Their Major Features in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	PROGRAM									VEHICLES								Inspection Frequency		TEST TYPE																	
			Type					Enforcement Methods				Type				Exempted						Safety	Emission				Tampering (Visual & Functional)												
EPA Region	State/ Area	m/y	CC	CL	CS	DC	OE	R	S	R+S	CM	ALL	LMYN	MY+	MW(lb)	AC	D	MC	OF	A	B		I	TSI	L	OP	Ainj	Aint	Cat	CM	EFC	EGR	EVS	FTI	OS	PCV	PMB	RCat	SS
III	Washington, D.C. - Citywide	01/83		X					X			X			6,000		X	X		X		X	X																
	Delaware - Wilmington (New Castle)	01/83			X			X				•		'68	8,500		X	X		X		X	X																
	Maryland - Baltimore (Anne Arundel, Baltimore, Carroll, Harford, Howard) - D.C. areas (Montgomery, Prince Georges)	02/84	X					X					12		10,000		X	X		X			X						X C.O.					X C.O.					
	Pennsylvania - Philadelphia (Bucks, Chester, Delaware, Montgomery, Philadelphia) - Pittsburgh (Allegheny, Beaver, Washington, Westmoreland) Allentown/ Bethlehem/Easton (Lehigh, Northampton)	06/84				X			X				25		11,000		X	X		X		X	X				X S.W.		X S.W.			X S.W.	X S.W.	X S.W.		X S.W.			X S.W.
	Virginia - D.C. Suburbs (Arlington, Fairfax Co., Prince William, Fairfax, Alexandria, Fall Church, Manassas, Manassas Park)	12/84				X				X			8		6,000	X	X	X		X		X	X								All applicable devices								

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Ainj - Air injection
Aint - Air intake
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JURISDICTION		Date of Start	PROGRAM									VEHICLES								Inspection Frequency		TEST TYPE																	
EPA Region	State/ Area		Type					Enforcement Methods				Type				Exempted						Safety	Emission				Tampering (Visual & Functional)												
		m/y	CC	CL	CS	DC	OT	R	S	R+S	CM	ALL	LMYN	MY+	MW(lb)	AC	D	MC	OF	A	B		I	TSI	L	OP	AInj	AInt	Cat	CM	EFC	EGR	EVS	FTI	OS	PCV	PMB	RCat	SS
IV	Georgia - Atlanta (Cobb, Dekalb, Fulton, Gwinnett)	04/82, 04/83*				X			X*	X			13		8,500		X	X		X			X				X		X			X	X	X		X			X
	Kentucky - Louisville (Jefferson)	01/84	X								X	X			10,000					X			X			X													
	Cincinnati - Suburbs (Boone, Kenton, Campbell)	11/86				X					X			'80	8,500		X	X		X							X		X				X	X	X	X	X	X	
	North Carolina - Charlotte (Mecklenburg)	12/82				X			X				12				X	X		X		X	X				X	X	X			X		X		X			
	- Raleigh (Wake)	11/86				X?																																	
	Tennessee - Nashville (Davidson)	01/85	X					X					13		8,500		X	X		X			X			X													
	- Memphis (Shelby)	08/83		X				X				X			8,500		X	X		X		X	X						X S.W.					X S.W.					

* For Gwinnett

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EPA Region	State/ Area		Type					Enforcement Methods				Type				Exempted						Safety	Emission				Tampering (Visual & Functional)												
		m/y	CC	CL	CS	DC	DY	R	S	R+S	CM	ALL	LMYN	MY+	MW(lb)	AC	D	MC	OF	A	B		I	TSI	L	OP	AInj	AInt	Cat	CM	EFC	EGR	EVS	FTI	OS	PCV	PHB	RCat	SS
V	Illinois - Chicago (Cook, Lake, Du Page) - E. St. Louis (Madison, St. Clair)	02/86	X						X		X			'68	8,000		X	X		X				X					X S.W.					X S.W.					
	Indiana - Chicago Suburbs (Lake, Porter) - Louisville Suburbs (Clark, Floyd)	06/84	X								X		12		10,000		X	X			X			X					X S.W.					X S.W.					
	Michigan - Detroit (Macomb, Oakland, Wayne)	12/85				X		X					9		8,500		X	X		X			X				X	X	X	X	X	X	X	X	X	X	X	X	X
	Wisconsin - Milwaukee (Kenosha, Milwaukee, Ozaukee, Racine, Washington, Waukesha)	04/84	X			X							15		8,000		X	X		X			X				X S.W.	X S.W.	X S.W.			X S.W.		X S.W.		X S.W.			

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EPA Region	State/Area		Type					Enforcement Methods				Type				Exempted						Safety	Emission				Tampering (Visual & Functional)												
		m/y	CC	CL	CS	DC	DT	R	S	R+S	CM	ALL	LMYN	MY+	MW(lb)	AC	D	MC	OF	A	B		I	TSI	L	OP	AInj	AInt	Cat	CM	EFC	EGR	EVS	FTI	OS	PCV	PMB	RCat	SS
VI	Oklahoma - Tulsa (Tulsa, Wagoner, Rogers, Creek, Osage)	01/86				X			X					'79	8,500		X	X	X	X		X					X	X	X			X	X	X	X	X	X	X	
	- Oklahoma City	05/87																																					
	Louisiana - Baton Rouge (E. Baton Rouge, W. Baton Rouge)	08/85				X			X					'68	6,000 for MY 68-79 8,500 for MY 80+		X	X	X	X		X					X MY80+	X MY80+	X MY80+			X MY80+	X MY80+	X MY80+	X MY80+	X MY80+	X MY80+	X MY80+	
	- Statewide (except New Orleans)																																						
	Texas - Houston (Harris)	07/86				X			X					'68	8,500		X	X	X	X		X					X	X	X MY80+			X	X	X MY80+	X MY80+	X	X MY80+	X MY80+	
	- Dallas (Dallas)	05/86																																					
	- Fort Worth (Tarrant)	05/86																																					
	- El Paso (El Paso)	01/87				X																		X															

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EPA Region	State/Area		Type					Enforcement Methods				Type				Exempted						Safety	Emission				Tampering (Visual & Functional)												
		m/y	CC	CL	CS	DC	[illegible]	R	S	R+S	CM	ALL	LMYN	MY+	MW(lb)	AC	D	MC	OF	A	B		I	TSI	L	OP	AInj	AInt	Cat	CM	EFC	EGR	EVS	FTI	OS	PCV	PMB	RCat	SS
VII	Missouri - St. Louis (St. Charles, St. Louis, St. Louis City, Jefferson)	01/84				X		X						'71	8,500		X	X	X	X		X	X		*		X	X	X MY81+			X	X	X MY81+		X			
VIII	Colorado - Denver (Adams, Arapahoe, Boulder, Denver, Douglas, Jefferson)	01/82				X			X					'68	10,000		X	X	X	X			X	X MY81+			X MY82+		X MY82+					X MY82+					
	- Colorado Springs (El Paso) - Fort Collins (Larimer)																																						
	Utah - Salt Lake City (Salt Lake)	04/84				X		X				X		'68			X	X		X		X	X				X MY84+ S.W. Pre-84		X MY84+ S.W. Pre-84					X MY84+ S.W. Pre-84					
	- Davis	06/84				X		X				X		'68			X	X		X		X	X							All applicable components for						MY 84+ S.W. Pre-84			
	- Provo	07/84				X		X				X		'68			X	X		X		X	X				X MY77+ S.W.MY 68-76		X MY77+ S.W.MY 68-76					X MY77+ S.W.MY 68-76			X MY77+ S.W.MY 68-76		

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(Source: 98)

JURISDICTION		Date of Start	PROGRAM									VEHICLES								Inspection Frequency		TEST TYPE																	
EPA Region	State/ Area		Type					Enforcement Methods				Type				Exempted						Safety	Emission				Tampering (Visual & Functional)												
		m/y	CC	CL	CS	DC	[illegible]	R	S	R+S	CM	ALL	LMYN	MY+	MW(lb)	AC	D	MC	OF	A	B		I	TSI	L	OP	AInj	AInt	Cat	CM	EFC	EGR	EVS	FTI	OS	PCV	PMB	RCat	SS
IX	Arizona - Phoenix (Maricopa) - Tucson (Pima)	01/77	X					X				X		'72			X			X			X						X F					X F			X F	X F	
	California - South Coast - Ventura - San Francisco - San Diego - Sacramento - Fresno - Bakersfield	03/84 10/84 01/85				X		X					20		8,500		X	X	X		X		X	X MY80+			X	X	X	X	X	X	X	X		X			X
	Nevada - Las Vegas (Clark) - Reno (Washoe)	10/83				X		X					20		5,000 curb wt.					X				X					C S.W. MY75+										

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MY+ - Model year and later
MW(lb) - Maximum weight (lb)

Vehicles Exempted

AC - Air cooled
D - Diesel
MC - Motorcycles
OF - Other fuels

Test Type

Emission

I - Idle
TSI - Two-speed idle
L - Loaded
OP - Opacity

Tampering (Visual & Functional)

AInj - Air injection
AInt - Air intake
Cat - Catalyst
CM - Computer module
EFC - Electronic fuel injection (Carburetor)
EGR - Exhaust gas recirculation
EVS - Evaporation system
FTI - Fuel tank inlet
OS - Oxygen sensor
PCV - Positive crankcase ventilation
PMB - Plumbtesmo
RCat - Replace catalyst if inlet tampered
SS - Spark system

C.O. - Change of ownership
S.W. - Seeking waiver
F - Failed

TABLE 5.2 (Contd)

Summary of the Status of I/M Programs and Their Major Features in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	PROGRAM									VEHICLES								Inspection Frequency		TEST TYPE																	
EPA Region	State/ Area		Type					Enforcement Methods				Type				Exempted						Safety	Emission				Tampering (Visual & Functional)												
		m/y	CC	CL	CS	DC	SV	R	S	R+S	CM	ALL	LMYN	MY+	MW(lb)	AC	D	MC	OF	A	B		I	TSI	L	OP	AInj	AInt	Cat	CM	EFC	EGR	EVS	FTI	OS	PCV	PMB	RCat	SS
X	Alaska - Anchorage (Anchorage)	07/85				X		X					15		12,000 curb wt.		X	X	X	X		X		X			X MY75+	X MY75+	X MY75+					X MY75+				X MY75+	
	- Fairbanks (North Star)	07/85				X		X						'75	12,000 curb wt.		X	X	X	X		X		X			X	X	X		X			X		X	X	X	
	Idaho - Boise (Ada)	08/84				X			X		X			'70	8,500		X	X	X	X			X				X MY84+		X MY84+					X MY84+					
	Oregon - Portland (Multnomah, Clackamas, Washington)	07/75			X			X				X	20		8,500		X	X			X		X MY Pre-81	X MY81+			X MY75+	X MY75+	X MY75+	X MY75+		X MY75+	X MY75+	X MY75+	X MY75+	X MY75+			X MY75+
	- Medford (Jackson)	01/86																																					
	Washington - Seattle (King, Snohomish)	01/82	X					X				X	13				X	X	X	X																			
	- Spokane (Spokane)	07/85																					X																

Key to Abbreviations

Program Type

CC - Central contractor
CL - Central local-run
CS - Central state-run
DC - Decentralized
(mannual or computer)

Program Enforcement Methods

R - Registration
S - Sticker
R+S - Registration and sticker
CM - Computer matching

Vehicles Type

ALL - All model years
LMYN - Last model year number
MY+ - Model year and later
MW(lb) - Maximum weight (lb)

Vehicles Exempted

AC - Air cooled
D - Diesel
MC - Motorcycles
OF - Other fuels

Test Type

Emission

I - Idle
TSI - Two-speed idle
L - Loaded
OP - Opacity

Tampering (Visual & Functional)

AInj - Air injection
AInt - Air intake
Cat - Catalyst
CM - Computer module
EFC - Electronic fuel injection (Carburetor)
EGR - Exhaust gas recirculation
EVS - Evaporation system
FTI - Fuel tank inlet
OS - Oxygen sensor
PCV - Positive crankcase ventilation
PMB - Plumbteamo
RCat - Replace catalyst if inlet tampered
SS - Spark system

C.O. - Change of ownership
S.W. - Seeking waiver
F - Failed

TABLE 5.3

Summary of the Emission Standards used in I/M Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	HC, ppm													CO, %												
			Model year													Model year												
EPA Region	State/ Area	m/y	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later
I	Connecticut - Statewide	01/83	750	650	600	575	425	425	300	300	300	300	300	275	220	7.5	7.0	6.0	6.0	6.0	6.0	3.0	3.0	3.0	3.0	3.0	2.5	1.2
	Massachusetts - Statewide	04/83			800	800	800	800	400	400	400	400	400	300	220			7.0	7.0	7.0	7.0	4.0	4.0	4.0	4.0	4.0	2.7	1.2
	New Hampshire - Dover (Rockingham Hillsborough)	08/87	←						N/A					→		←						N/A						→
	Rhode Island - Statewide	01/79	1000 -800	800	800	800	800	600	300	300	300	300	300	300	300	10.0 -8.0	8.0	8.0	8.0	8.0	8.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
II	New Jersey - Statewide	02/74	1400 -700	700	500	500	500	300	300	300	300	300	300	300	220	8.5 -7.0	7.0	5.0	5.0	5.0	5.0	3.0	3.0	3.0	3.0	3.0	3.0	1.2
	New York - New York City Metro Area (Bronx, Kings, Nassau, New York, Queens, Richmond, Rockland, Suffolk Westchester)	01/82	←					700	600	600	600	600	300	300	220	←						6.0	5.5	3.0	3.0	3.0	3.0	1.2

N/A - Information not available

TABLE 5.3 (Contd)

Summary of the Emission Standards used in I/M Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	HC, ppm													CO, %												
			Model year													Model year												
EPA Region	State/ Area	m/y	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later
III	Washington, D.C. - Citywide	01/83	2000 -1250	1250	1200	1200	1200	1200	600	600	500	600	600	300	300	12.5 -11.0	11.0	9.0	9.0	9.0	9.0	6.5	6.5	6.5	6.5	6.5	3.0	1.5
	Delaware - Wilmington (New Castle)	01/83	1000	1000	700	700	700	700	450	450	450	450	450	275	220	Not Applicable												
	Maryland - Baltimore (Anne Arundel, Baltimore, Carroll, Harford, Howard) D.C. areas (Montgomery, Prince Georges)	02/84						600	450	450	350	350	350	300	220						6.0	5.5	4.5	5.5	3.5	3.0	3.0	1.2
	Pennsylvania - Philadelphia (Bucks, Chester, Delaware, Montgomery, Philadelphia)	06/84	1500 -600	600	600	600	600	600	400	400	400	400	400	300	220	10.0 -6.0	6.0	6.0	6.0	6.0	6.0	4.0	4.5	4.0	4.0	4.0	3.0	1.2
	- Pittsburgh (Allegheny, Beaver Washington, Westmoreland) Allentown/ Bethlehem/Easton (Lehigh, Northampton)																											
	Virginia - D.C. Suburbs (Arlington, Fairfax Co., Prince William, Fairfax, Alexandria, Fall Church, Manassas, Manassas Park)	12/81										400	400	220	220										4.0	4.0	3.0	1.2

TABLE 5.3 (Contd)

Summary of the Emission Standards used in I/M Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	HC, ppm												
			Model year												
EPA Region	State/ Area	m/y	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later
IV	Georgia - Atlanta (Cobb, DeKalb, Fulton, Gwinnett)	04/82; 04/85*						600	600	600	600	600	600	250	220
	Kentucky - Louisville (Jefferson)	02/84	950 -900	800	850	800	800	800	750	750	650	600	550	300	220
	Cincinnati - Suburbs (Boone, Kenton, Campbell)		Not Applicable												
	North Carolina - Charlotte (Mecklenburg)	12/82	Not Applicable												
	- Raleigh (Wake)	11/84													
	Tennessee - Nashville (Davidson)	04/85					500	500	300	300	300	300	300	300	220
	- Memphis (Shelby)	08/82			1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500

JURISDICTION		Date of Start	CO, %												
			Model year												
EPA Region	State/ Area	m/y	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later
IV	Georgia - Atlanta (Cobb, DeKalb, Fulton, Gwinnett)	04/82; 04/85*						4.0	4.0	4.0	4.0	4.0	4.0	3.0	1.2
	Kentucky - Louisville (Jefferson)	02/84	8.5	8.4	8.1	8.0	7.8	7.6	6.5	6.5	6.2	5.5	4.0	3.0	1.2
	Cincinnati - Suburbs (Boone, Kenton, Campbell)		Not Applicable												
	North Carolina - Charlotte (Mecklenburg)	12/82						7.0	5.0	5.0	5.0	5.0	5.0	3.0	1.2
	- Raleigh (Wake)	11/84													
	Tennessee - Nashville (Davidson)	04/85					5.0	5.0	3.0	3.0	2.0	2.0	2.0	2.0	1.2
	- Memphis (Shelby)	08/82			9.0	9.0	9.0	9.0	8.5	8.5	8.5	8.5	8.5	[illegible]	3.0

TABLE 5.3 (Contd)

Summary of the Emission Standards used in I/M Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	THC, ppm													CO, %												
			Model year													Model year												
EPA Region	State/ Area	m/y	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later
V	Illinois - Chicago (Cook, Lake, Du Page) - E. St. Louis (Madison, St. Clair)	05/86	900	900	900	800	800	800	700	700	700	600	600	300	220	9.0	9.0	9.0	8.0	8.0	8.0	7.0	7.0	7.0	6.0	6.0	3.0	1.2
	Indiana - Chicago Suburbs (Lake, Porter) - Louisville Suburbs (Clark, Floyd)	06/84					500	500	450	450	450	350	350	250	220					7.0	7.0	6.5	6.5	6.5	5.5	5.5	3.0	1.2
	Michigan - Detroit (Macomb, Oakland, Wayne)	12/82									900	700	500	300	330									6.0	5.5	4.0	3.0	1.2
	Wisconsin - Milwaukee (Kenosha, Milwaukee, Ozaukee, Racine, Washington, Waukesha)	04/84			800	700	700	700	600	600	500	450	400	275	220			8.0	7.0	7.0	7.0	6.0	6.0	6.0	4.0	4.0	2.5	1.2

TABLE 5.3 (Contd)

Summary of the Emission Standards used in I/M Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	HC, ppm													CO, %												
			Model year													Model year												
EPA Region	State/ Area	m/y	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later
VI	Oklahoma - Tulsa (Tulsa, Wagoner, Rogers, Creek, Osage)	01/86	Not Applicable													Not Applicable												
	- Oklahoma City	01/87																										
	Louisiana - Baton Rouge (E. Baton Rouge, W. Baton Rouge)	09/85	Not Applicable													Not Applicable												
	- Statewide (except New Orleans)																											
	Texas - Houston (Harris)	07/84	Not Applicable													Not Applicable												
	- Dallas (Dallas)	01/86																										
	- Fort Worth (Tarrant)	01/86																										
	- El Paso (El Paso)	01/87																										

TABLE 5.3 (Contd)

Summary of the Emission Standards used in I/M
Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	THC, ppm													CO, %												
			Model year													Model year												
EPA Region	State/ Area	m/y	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later
VII	Missouri - St. Louis (St. Charles, St. Louis, St. Louis City, Jefferson)	01/84			700	700	700	700	600	600	600	600	600	300	220			7.0	7.0	7.0	7.0	6.0	6.0	6.0	6.0	6.0	3.0	1.2
VIII	Colorado - Denver (Adams, Arapahoe, Boulder, Denver, Douglas, Jefferson)	01/82	1200	1200	1200	1200	1200	1200	800	800	700	500	400	400	400	6.0	6.0	6.0	5.4	5.4	5.4	5.0	5.0	3.6	3.6	2.0	1.5	1.5
	- Colorado Springs (El Paso) - Fort Collins (Larimer)																											
	Utah - Salt Lake City (Salt Lake)	04/84	800	700	700	700	700	700	600	600	500	500	500	300	220	8.0	7.0	7.0	7.0	7.0	7.0	6.0	6.0	5.0	5.0	5.0	3.0	1.2
	- Davis	04/84	800	700	700	700	700	700	600	600	500	500	500	300	220	8.0	7.0	7.0	7.0	7.0	7.0	6.0	6.0	5.0	5.0	5.0	3.0	1.2
	- Provo	07/84	1500	1200	1200	1200	1200	1200	1000	1000	800	800	800	600	220	6.0	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	3.0	3.0	1.2

TABLE 5.3 (Contd)

Summary of the Emission Standards used in I/M Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	HC, ppm													CO, %												
			Model year													Model year												
EPA Region	State/ Area	m/y	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later
IX	Arizona	01/77		4CYL →		600	400	400	350	350	350	300	220	220	220		4 Cyl →		5.5	5.5	5.0	2.2	2.2	2.2	2.2	2.2	1.2	1.2
	- Phoenix								← under 6,000 lb. →													← under 6,000 lb. →						
	(Maricopa)								350	350	350	300					6-8 Cyl →		5.5	5.5	5.5	4.0	4.0	4.0	4.0	2.2	1.2	1.2
	- Tucson								← over 6,000 lb. →													← over 6,000 lb. →						
	(Pima)			6-8 CYL →		600	400	400	250	250	250	250	300	300	300											3.0	1.2	1.2
	California	03/84																										
	- South Coast								Cutpoints established by combinations of model year, number of cylinders, and type of emission control system.																			
	- Ventura																											
	- San Francisco																											
	- San Diego																											
	- Sacramento																											
	- Fresno	10/84																										
	- Bakersfield	01/86																										
	Nevada	10/83	← Not Applicable →													6.0	6.0	5.5	5.5	5.0	5.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0 1.2([illegible])
	- Las Vegas (Clark)																											
	- Reno (Washoe)																											

TABLE 5.3 (Contd)

Summary of the Emission Standards used in I/M
Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	THC, ppm													CO, %												
			Model year													Model year												
EPA Region	State/ Area	m/y	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later	Pre-1970	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 and Later
X	Alaska - Anchorage (Anchorage)	07/85				Cutpoints established by model year and weight.																						
	- Fairbanks (North Star)	07/85																										
	Idaho - Boise (Ada)	08/84	← Not Applicable →														5.5	5.5	5.5	5.5	5.5	3.5	3.5	3.5	3.5	2.5	1.5	1.2
	Oregon - Portland (Multnomah, Clackamas, Washington)	07/75								Cutpoints established by model year and make.						Most 1975+ vehicles: HC-225 ppm, CO - 1.0%.												
	- Medford (Jackson)	01/86																										
	Washington - Seattle (King, Snohomish)	01/82					1,000	1,000	800	800	800	800	600 300	600 ← no catalyst → 300 ← with catalyst →	600 300			4 Cyl. →		6.0	6.0	3.0	3.0	3.0	3.0	3.0 2.0	3.0 ← no catalyst → 2.0 ← with catalyst →	3.0 2.0
	- Spokane (Spokane)	07/85																6-8 Cyl. →		5.0	5.0	3.0	3.0	3.0	3.0	3.0 1.5	3.0 ← no catalyst → 1.5 ← with catalyst →	3.0 1.5

TABLE 5.4

Summary of Repair Cost Waiver Type and Inspection Cost in I/M Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	WAIVER TYPE					COST	
EPA Region	State/ Area	m/y	CW $	RDN %	SR	TRCX	NONE	$	S.F. Incl.
I	**Connecticut** - Statewide	01/83	40			X		10	
	Massachusetts - Statewide	04/83	100% or 10% of value		X	X		10	
	New Hampshire - Nashua (Rockingham Hillsborough)	09/87	N/A					N/A	
	Rhode Island - Statewide	01/79					X	4	X
II	**New Jersey** - Statewide	02/74					X	2.50 -12.00	X
	New York - New York City Metro Area (Bronx, Kings, Nassau, New York, Queens, Richmond, Rockland, Suffolk Westchester)	01/82			X			7	

N/A - Information not available

KEY TO ABBREVIATIONS

CW - Cost Waiver,
SR - Stated Repair,
S.F. - Safety Fee

RDN - Reduction
TRCX - Tamper Repair Cost Excluded

TABLE 5.4 (Contd)

Summary of Repair Cost Waiver Type and Inspection Cost in I/M Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	WAIVER TYPE					COST	
EPA Region	State/ Area	m/y	CW $	RDN %	SR	TRCX	NONE	$	S.F. Incl.
III	**Washington,D.C.** - Citywide	01/83	None					5	X
	Delaware - Wilmington (New Castle)	01/83	75					None	
	Maryland - Baltimore (Anne Arundel, Baltimore, Carroll, Harford, Howard) - D.C. areas (Montgomery, Prince Georges)	02/84	50		X	X		9	
	Pennsylvania - Philadelphia (Bucks, Chester, Delaware, Montgomery, Philadelphia) - Pittsburgh (Allegheny, Beaver Washington, Westmoreland) Allentown/ Bethlehem/Easton (Lehigh, North-Hampton)	06/84	25 MY Pre-75 50 MY 75+			X		5	
	Virginia - D.C. Suburbs (Arlington, Fairfax Co., Prince William, Fairfax, Alexandria, Fall Church, Manassas, Manassas Park)	12/81	75 or SR		X	X		5	

KEY TO ABBREVIATIONS

CW - Cost Waiver,
SR - Stated Repair,
S.F. - Safety Fee
RDN - Reduction
TRCX - Tamper Repair Cost Excluded

TABLE 5.4 (Contd)

Summary of Repair Cost Waiver Type and Inspection Cost in I/M Programs in the U.S.A..

(Source: 98)

JURISDICTION		Date of Start	WAIVER TYPE					COST	
EPA Region	State/ Area	m/y	CW $	RDN $	SR	TRCX	NONE	$	S.F. Incl.
IV	**Georgia** - Atlanta (Cobb, Dekalb, Fulton, Gwinnett)	04/82, 04/85*	50			X		5	
	Kentucky - Louisville (Jefferson)	01/84	Varies by MY and failure type	Any				6	
	Cincinnati - Suburbs (Boone, Kenton, Campbell)	11/86					X	6	
	North Carolina - Charlotte (Mecklenburg)	12/82	50			X		10 Max.	X
	- Raleigh (Wade)	11/86							
	Tennessee - Nashville (Davidson)	01/85					X	6	
	- Memphis (Shelby)	08/83	50 or SR		X	X		None	

* For Gwinnett

KEY TO ABBREVIATIONS

CW - Cost Waiver,
SR - Stated Repair,
S.F. - Safety Fee
RDN - Reduction
TRCX - Tamper Repair Cost Excluded

TABLE 5.4 (Contd)

Summary of Repair Cost Waiver Type and Inspection Cost in I/M Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	WAIVER TYPE					COST	
EPA Region	State/ Area	m/y	CW $	RDN %	SR	TRCX	NONE	$	S.F. Incl.
V	**Illinois** - Chicago (Cook, Lake, Du Page) - E. St. Louis (Madison, St. Clair)	05/86			X			None	
	Indiana - Chicago Suburbs (Lake, Porter) - Louisville Suburbs (Clark, Floyd)	06/84	50 (Parts) 100 (Parts+ labour)	40				None	
	Michigan - Detroit (Macomb, Oakland, Wayne)	12/85	65		X	X			
	Wisconsin - Milwaukee (Kenosha, Milwaukee, Ozaukee, Racine, Washington, Waukesha)	04/84	55		10-Yr. Old	X		None	

KEY TO ABBREVIATIONS

CW - Cost Waiver,
SR - Stated Repair,
S.F. - Safety Fee
RDN - Reduction
TRCX - Tamper Repair Cost Excluded

TABLE 5.4 (Contd)

Summary of Repair Cost Waiver Type and Inspection Cost in I/M Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	WAIVER TYPE					COST	
EPA Region	State/ Area	m/y	CW $	RDN $	SR	TRCX	NONE	$	S.F. Incl.
VI	**Oklahoma** - Tulsa (Tulsa, Wagoner, Rogers, Creek, Osage)	01/86					X	5.00	
	- Oklahoma City	01/87							
	Louisiana - Baton Rouge (E. Baton Rouge, W. Baton Rouge)	09/85					X	6.50	
	- Statewide (except New Orleans)								
	Texas - Houston (Harris)	07/84					X	2.75 MY80+	
	- Dallas (Dallas)	01/86							
	- Fort Worth (Tarrant)	01/86							
	- El Paso (El Paso)	01/87							

KEY TO ABBREVIATIONS

CW - Cost Waiver,
SR - Stated Repair,
S.F. - Safety Fee
RDN - Reduction
TRCX - Tamper Repair Cost Excluded

TABLE 5.4 (Contd)

Summary of Repair Cost Waiver Type and Inspection Cost in I/M Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	WAIVER TYPE					COST	
EPA Region	State/ Area	m/y	CW $	RDN %	SR	TRCX	NONE	$	S.F. Incl.
VII	Missouri - St. Louis (St. Charles, St. Louis, St. Louis City, Jefferson)	01/84			X			4.50 Max.	
VIII	Colorado - Denver (Adams, Arapahoe, Boulder, Denver, Douglas, Jefferson)	01/82	100 MY81+		15 MY68-80	X		10 Max.	
	- Colorado Springs (El Paso - Fort Collins (Larimer)								
	Utah - Salt Lake City (Salt Lake)	04/84	100 MY82+		15 MYPre-82	X		9 Max.	
	- Davis	04/84	60-150			X		9 Max.	
	- Provo	07/86	100 MY81+		15 MYPre-81	X X		9 Max.	

KEY TO ABBREVIATIONS

CW - Cost Waiver,	RDN - Reduction
SR - Stated Repair,	TRCX - Tamper Repair Cost Excluded
S.F. - Safety Fee	

TABLE 5.4 (Contd)

Summary of Repair Cost Waiver Type and Inspection Cost in I/M Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	WAIVER TYPE					COST	
EPA Region	State/ Area	m/y	CW $	RDN %	SR	TRCX	NONE	$	S.F. Incl.
IX	Arizona	01/77	50 or 10%			X		5.93	
	- Phoenix (Maricopa)								
	- Tucson (Pima)								
	California	03/84	50			X		27 Avg.	
	- South Coast								
	- Ventura								
	- San Francisco								
	- San Diego								
	- Sacramento								
	- Fresno	10/84							
	- Bakersfield	01/86							
	Nevada	10/83			14 MYPre-82			8.50	
	- Las Vegas (Clark)								
	- Reno (Tahoe)		100 MY82+			X			

KEY TO ABBREVIATIONS

CW - Cost Waiver,
SR - Stated Repair,
S.F. - Safety Fee
RDN - Reduction
TRCX - Tamper Repair Cost Excluded

TABLE 5.4 (Contd)

Summary of Repair Cost Waiver Type and Inspection Cost in I/M Programs in the U.S.A.

(Source: 98)

JURISDICTION		Date of Start	WAIVER TYPE					COST	
EPA Region	State/ Area	m/y	CW $	RDN %	SR	TRCX	NONE	$	S.F. Incl.
X	Alaska - Anchorage (Anchorage)	07/85	300 150 for tampering					50 Max.	
	- Fairbanks (North Star)	07/85	150 300 for tampering					35 Max.	
	Idaho - Boise (Ada)	08/84			15 MYPre-81 30 MY81+				
	Oregon - Portland (Multnomah, Clackamas, Washington)	07/75					X	7	
	- Medford (Jackson)	01/86							
	Washington - Seattle (King, Snohomish)	01/82	50					10	
	- Spokane (Spokane)	07/85							

KEY TO ABBREVIATIONS

CW - Cost Waiver,	RDN - Reduction
SR - Stated Repair,	TRCX - Tamper Repair Cost Excluded
S.F. - Safety Fee	

Table 5.5

Summary of the Major Features of All I/M Programs in the U.S.A.

Program Feature	Total Number of Programs
Test Type	
Safety + Emission + Tamper (any)	15
Safety + Emission	7
Safety + Tamper (any)	3
Emission + Tamper (any)	13
Emission	3
Tamper (any)	1
Plumbtesmo	8
Inspection	
Centralized Contractor	9
Centralized Local	2
Centralized State	2
Decentralized (Computer + Manual)	23
Hybrid	1
Frequency	
Annual	36
Biennial	3
Enforcement	
Computer Matching	5
Registration	19
Registration + Sticker	1
Sticker	16
Vehicles Included	
All years	8
Limited by Vehicle Age	33
Limited by Gross Vehicle Weight	42
Motor Cycle	2
Diesel Engine	1
Vehicles Excluded	
None	1
Motor Cycles	45
Diesel Engine	46
Other Fuels	11

Note: As there are some sub-areas within a program jurisdiction and some have different or a combination of features, the total number of features within a category may be different from the total number of programs

Source: 98

Emission tests are carried out to determine the vehicle compliance with the standards established particularly for that kind of tests. These tests are intended for measuring THC and CO only, and in 28 of the programs listed both of these contaminants are measured. However, in 3 programs only CO is determined and in another program only THC is measured. The emission standards used to determine compliance with these vary from program to program, and within a program, according to vehicle model year in most cases. In some cases, it also varies with engine size. The standard for CO for 1981 model year and after vehicles varies from 1.0% in California to 3.0% in three states. As for THC, the standard for similar vehicles ranges from 100 ppm in California to 1990 ppm in Memphis, Tennessee.

Most of the programs (23) are decentralized and the remainder are of centralized type, except the one at New Jersey which is termed as "hybrid" type. It should be noted the program for the District of Columbia and suburbs consists of both centralized and decentralized inspection facilities.

The frequency of inspection in all programs is annual with the exception of those in Indiana, California and Oregon, where inspections are performed biennially.

There appears to be two prevalent methods of enforcing the inspection part of the I/M program, namely "registration" and "sticker." While in 19 programs the "registration" method is used, the latter system is employed in 16 programs. There is one program for the Washington D.C. suburbs where both of the above systems are used to enforce the program. A "computer matching" technique is used in 5 programs only.

In most of the programs the vehicles included are limited by the vehicle age. Vehicles of all model years are inspected in 8 programs only. There are also varying restrictions on test vehicles based on gross vehicle weight in all but one of the programs. Two of the programs do inspections on motorcycles, and one program also includes diesel vehicles up to 18,000 lbs. of gross weight.

Only one of the programs has no excluded category of vehicles, while nearly all other programs exclude both motorcycles and diesel-engined vehicles with the exceptions mentioned earlier. There are 11 programs where vehicles using other fuels, besides gasoline and diesel, are not inspected.

To relieve the vehicle owners from the burden of the repair costs incurred as a result of vehicles failing the I/M tests, most programs grant some kind of cost waiver. A vehicle owner is thus exempted from additional repairs after retest, if the costs incurred are above a pre-established limit. The range of such cost waiver varies from $14 in Nevada to $300 in Alaska, with a multitude of variations based on different factors. About 67% of the programs with provisions for cost waiver do not allow any such benefit to the vehicle owners when any kind of tampering with emission control devices is involved. There are no repair cost waiver in eight I/M programs.

The fee charged for inspection varies with the type of program. There are 5 programs where the inspection is given free of charge, and in 4 programs the fee also covers a safety inspection. With the exception of programs in Alaska and California, the inspection fee in all other programs ranges from $2.50 to $12.00. In Alaska the fee is $50, and in California it varies but an average of $27 has been reported.

The non-uniformity of the various features of the I/M programs in the U.S.A. results from both technical reasons and the program development and administration responsibilities, as will be discussed in the following sections.

6. CHARACTERISTICS OF THE MAJOR FEATURES OF I/M PROGRAMS

As the name implies an I/M program consists of two primary functions - the inspection of vehicles to identify "high emitters" and the maintenance, as well as reinspection, of the latter to bring them into "compliance". The high or excess emissions and compliance are determined on the basis of emission standards applicable to particular vehicles, as will be discussed later. Both the above functions can be classified into various program features, each with several alternatives or options, and some are also inter-related. As indicated in the previous section, there are numerous alternative parameters within each major feature of the I/M programs implemented in the U.S.A. In this section only the essential elements of the major features of these programs are discussed.

It should be noted, however, that the main reason behind the variations in I/M program details in the U.S.A. appears to be the separate responsibilities of the federal and state governments in controlling air pollution. Under the Clean Air Act, EPA may require the states to implement I/M programs in certain air quality non-attainment areas, and provide guidance to the states in the form of minimum requirements. Although subject to approval by EPA, the states are responsible for the details of their respective I/M program design and implementation. As the state authorities do consider various area-specific situations in designing such a program, it has resulted in a number of alternative program elements in the U.S.A. Another possible reason for these variations is the compromises often made between some of the technical recommendations and socio-political situations.

6.1 Inspection Test

Until July 1984 when the I/M program in Harris County, Texas started, the "conventional" I/M program in the U.S.A. always included an exhaust emission test to identify vehicles with high emissions. In some jurisdictions besides emission test, certain visual and/or functional examination of devices and control systems related to emissions as well as of misfueling is also a part of the inspection. The I/M program in Texas and those in two other states, already implemented or proposed recently, are based primarily on the inspection for any tampering of emission control systems and related components, as well as on the tests for misfueling and misfiring. A comprehensive mechanic training is also a part of such programs. This latter type is usually referred to as an anti-tampering (ATP) program.

6.1.1 Emission Test

To carry out inspection of tail-pipe emissions various short tests have been developed over the years, as the standard FTP is unsuitable for use at an inspection station. According to Elston[54] as many as sixteen short emission tests have been proposed for inspection purpose in I/M programs. However, because of certain drawbacks associated with the majority of these tests, EPA has recommended three short tests as suitable for both I/M programs and Emission Performance Warranty[79]. These tests are: idle, two-speed idle, and two-mode loaded. The detailed procedures for these tests are described elsewhere[79].

The majority of the I/M programs with emission tests uses the idle test which is the simplest of the three tests mentioned above, while the rest employs two-speed idle test[98]. In some jurisdictions both idle and two-speed idle tests are used, but the latter to inspect the emissions from post-1981 MY vehicles only. Currently, a few states and localities are considering two-mode loaded test and only in Arizona a loaded mode is used as "preconditioning" certain types of vehicles for their idle test[79, 100]. The commonly used term "preconditions" is described in a subsequent section.

Briefly, in the short tests tailpipe emissions are measured by inserting a sampling probe inside the exhaust pipe directly, or through an extension adapter, while the vehicle is run stationary at the desired condition. In simple idle test the vehicle is operated at curb idle in neutral or park position. Two-speed idle test consists of sampling the vehicle's exhaust gas concentrations at curb idle, 2500 rpm speed, and at idle again after the engine has returned to curb idle. All measurements are made while the vehicle is in neutral or park. The engine's speed is measured by means of a tachometer. The simplified two-mode loaded test is carried out at 30 miles/hour cruise speed at 9.0 horse-power load followed by an idel in neutral. A dynamometer is needed to supply the desired load during this steady state testing.

The exhaust gas samples are continuously passed through emission analysers during a test, and the concentrations of pollutants are recorded once they are stabilized under the desired test mode. In the unloaded tests, only THC and CO concentrations in the tail-pipe emission are analysed, as no or insignificant quantity of NO_x is produced during idle and two-speed idle modes of the vehicle's operation. To ensure that the THC and CO concentrations in the sample are representative of the exhaust gas, it is essential that the sampling probe is inserted far enough inside the tail-pipe to avoid sample dilution. Such dilution can also occur if there is any leakage in the exhaust system. An analysis of the exhaust sample for its CO_2 content can identify excessive dilution, and this is regularly used in California[99].

As mentioned above, neither the unloaded or steady state loaded procedures determine the actual mass of contaminant emissions produced, only their concentrations are measured. This is the major significant difference, besides the test procedure, between the FTP and short emission tests. The new vehicle emission standards are based on mass emissions of contaminants determined by the FTP, and applicable during the useful life (5 years or 80,000 km) of a vehicle. For compliance purposes, an age deterioration factor based on vehicle type and MY is applied to the FTP emission test results determined at 6,400 km[70, 75]. However, for the reasons discussed above these standards are not applicable to the short emission tests employed in I/M programs.

6.1.1.1 Emission Standards

Under the requirements of Clean Air Act, Section 207 (b), EPA has established emission standards or cutpoints for short emission tests which are "reasonably capable of being correlated" with FTP standards[79]. It should be noted, however, that because of the inherent differences in the test procedures yielding different emision characteristics, no classical correlation can ever be established between FTP and short test emissions. The classical correlation requires some kind of mathematical relationship. In view of this EPA has taken the approach that a short test should be capable of accurately identifying vehicles with emissions in excess of the appropriate FTP standards. Another important aspect of this approach is to achieve a reasonable pass-fail correlation between these tests, by selecting short test emission standards to minimize the probability of the number of false short test failures[55, 79].

On the basis of the above criteria, vehicles tested by FTP and a short test can fall into four categories:

- vehicles pass both tests,

- vehicles fail both tests,
- vehicles pass FTP, but fail short test, and
- vehicles pass short test, but fail FTP.

If all vehicles fell in the first or second categories, ideal correlation between the two test standards would result. The vehicles under the third category is wrongly identified as having excess emissions. This is called an error of commission (EC). Under the last category the short test fails to identify high-emitting vehicles. This is termed as an error of omission (EO)[79].

As the main objective is to identify those vehicles with excess emissions, it is obvious that short test standards could be adjusted to minimize EC at the expense of increasing EO. EPA[79] considers that an EC of approximately 5%, the same as that for the FTP, is acceptable, and that the EO vehicle tend to exceed FTP standards by a moderate amount only.

Based on the test data, EPA has recommended[101] idle test emission standards for THC and CO applicable to various categories of passenger vehicles, as shown in Table 6.1. For 1981 and later model year vehicles, EPA has also recommended standards, as shown in Table 6.2, for the other two types of short tests mentioned above. In setting these emission standards for 1981 and later MY vehicles, EPA has indicated that based on the analysis of future test data, more stringent standards may be proposed in the future, if necessary[79].

Environment Canada[76] has suggested that the most desirable emission standards for THC and CO should be those specified by the vehicle manufacturer on the underhood label. Considering the normal engine wear, such label limits may

TABLE 6.1

Emission Standards Recommended by EPA for I/M Programs for 30% Stringency Factor

Vehicle Category (Model Year)	THC (ppm)	CO (%)
Pre-1968	1400	8.5
1968-1971	750	7.5
1972-1974	650	6.5
1975-1979	500	5.0
1980	300	3.0
Post-1980	220	1.2

Source: 99

TABLE 6.2

Initial Emission Standards Recommended by EPA for 1981 and Later MY Vehicles

Short Test Type	Standards		Test Equipment
	THC (ppm)	CO (%)	
Idle	220	1.2	Garage Analyser
Two-speed Idle: 1. Idle 2. 2500 rpm 3. Idle	200*	1.0*	Garage Analyser Tachometer
Two Mode Loaded: 1. 30 mph/9.0 hp 2. Idle	220**	1.2**	Garage Analyser Dynamometer

* Standards apply to the lowest HC and lowest CO emissions observed during the two idle portions of the test. Standards also apply to the 2500 rpm mode either independently or in conjunction with the idle portions.

** Standards apply to the loaded mode and idle, either in combination or independently.

Note: All idles are in neutral.

Source: 79

be extended to a maximum value at the rate of 0.1% per year of vehicle age for % CO and 30 ppm per year of vehicle age for ppm of THC. In the absence of any underhood label specification, the emission limits shown in Table 6.3 may be used. The emission standards used by the Ministry of Environment in Ontario[96] for short tests are shown in Table 5.1.

The short test emission standards or "207 (b)' cutpoints as commonly called, recommended by the EPA are primarily for the Emission Performance Warranty as mentioned earlier, although these could be used in the I/M programs, if a stringency factor or vehicle failure rate of 30% is employed. A review of the cutpoints used in the existing I/M programs in the U.S.A., as shown in Table 5.3, indicates that none of the programs has exactly the same THC and CO emission standards for vehicles of different model years as those suggested by the EPA. This may be partly because some local authorities consider variations in emission control systems are often more significant than differences in the vehicle model year[99]. The other reason is reportedly the method of selecting the suitable cutpoints which would yield the stringency factor or the desired failure rate in a particular I/M program area[101]. Cutpoints may need to be revised as the program progresses to control the overall failure rate at the level desired for emission reductions, to adjust the average failure rate within cutpoint categories, and to adjust the waiver rates[102].

6.1.1.2 Vehicle Preconditioning for Emission Test

The short idle test is not always able to identify certain vehicles with excess emissions. Such failures to recognize these vehicles are reportedly due partly to the new types of emission control system, but largely because of the lack of

TABLE 6.3

Emission Standards Suggested by Environment Canada for I/M Programs

Vehicle Age	2500 rpm Test				Idle Test			
	6 & 8 Cylinder Engine		4 Cylinder Engine		6 & 8 Cylinder Engine		4 Cylinder Engine	
	CO (%)	THC (ppm)	CO (%)	THC (ppm)	CO (%)	THC (ppm)	CO (%)	THC (ppm)
0-1	1.0	200	1.5	200	1.5*	300	2.5*	300
2	1.1	230	1.6	230	1.6	330	2.6	330
3	1.2	260	1.7	260	1.7	360	2.7	360
4	1.3	290	1.8	290	1.8	390	2.8	390
5	1.4	320	1.9	320	1.9	420	2.9	420
6	1.5	350	2.0	350	2.0	450	3.0	450
7	1.6	380	2.1	380	2.1	480	3.1	480
8	1.7	410	2.2	410	2.2	510	3.2	510
9	1.8	440	2.3	440	2.3	540	3.3	540
10	1.9	470	2.4	470	2.4	570	3.4	570

* The existing MVSA new vehicle emission standards for the idle test.

Source: 76

proper warming up of the vehicle engine prior to the actual sampling of the exhaust emissions[55, 79, 103]. To increase the effectiveness of the idle neutral test to recognize vehicles failing "207 (b)" cut-points for CO and THC, the EPA has recommended preconditioning of vehicles by running them either at the higher speed (2500 rpm) of the two-speed idle or under loaded condition of the two-mode loaded test for some time before actual sampling under idle condition[79].

Such preconditioning of vehicles for idle test is likely to ensure sufficient identification of high emitters, relative to the applicable standards and stringency factor, so that the error of commission rate is approximately the same as for the FTP.

6.1.1.3 Stringency Factor

As mentioned above the emission standards or cutpoints for each contaminant are established by the local agency responsible for the I/M programs for different vehicle type and model year. The pass/fail criteria of the vehicles tested are based on these specific cutpoints. However, as the failed vehicles must receive enough repairs to reduce their emission levels and pass a reinspection, there are several factors which an agency usually considers before deciding on the stringency factor and the emission standards. Some of these factors are the number of failing vehicles manageable in terms of the available capacity of the repair service industry to fix them and the ability of the I/M program to reinspect them, the inconvenience to the vehicle owners, and the overall cost involved[100]. At the same time the agency should also strive for the necessary emission reductions to achieve the desired air quality benefit.

The cutpoints established on this basis would result in an initial failure rate equal to the stringency factor, i.e. a 30% stringency means a 30% failure rate in the program.

The stringency factor used in the I/M programs in the U.S.A. ranges from 20% to 37%[55]. It has been suggested by the EPA that cutpoints should be based on the analysis of data from a representative sample of vehicles in the area where an I/M program would be established[101].

It is logical to expect that more vehicles will fail an inspection if either the stringency factor is increased for specific cutpoints or stricter cutpoints are used at the desired failure rate. However, studies by the EPA have shown that the program effectiveness, both in terms of emission reduction and cost, does not improve significantly beyond a 30% failure rate at the EPA recommended cutpoints for both pre-1981 and post-1981 vehicles[101, 104]. There are diminishing returns from failing more vehicles as more and more relatively clean cars will require repair and which will result in less and less cost-effective emission reductions than in the basic program.

6.1.1.4 Emission Analysers

The current I/M programs in the U.S.A. which include an exhaust emission test are designed to measure either CO or THC, or both, to determine a vehicle's compliance with the applicable emission standards. In order to avoid a high error of commission, by wrongly failing vehicles which would pass the FTP standard, or vice versa, it is paramount that the concentrations of these contaminants are measured accurately. In the older programs simple infrared gas analysers for CO and THC developed by the Bureau of Automotive Repair (BAR) in California, and commonly known as BAR-74, were used[99]. These analysers do not have any automatic system for zero and span calibrations or any means of checking for an excessive dilution of sample. These instruments, as well as a later version BAR-80, do not have provision for automatic data recording or reporting. Recent developments in analytical instruments have made it possible to use automated computerized analysers such as BAR-84, which have overcome most of the drawbacks of the earlier devices, in I/M test facilities[99, 104, 105].

The experience with I/M programs has shown that the incidences of vehicles being deliberately failed incorrectly, particularly in decentralized programs, do occur which generate complaints from vehicle owners[97, 99, 104]. To deter such fraudulent practices as well as to avoid bad publicity about I/M programs, installation of sophisticated emission analysers is considered to be an important feature of a program. These analysers are reliable and sufficiently accurate to reduce errors in failing or passing of vehicles, less prone to improper use, and can record and store all test data for subsequent checking. The latter function also reduces the administrative costs and time of the regulatory agency necessary for surveillance and program audit.

6.1.2 Anti-Tampering Check and Test

In recent years several regulatory agencies in the U.S.A. have introduced measures to check and/or test to determine tampering of emission control equipment and related components. Such measures have been added as a supplement to the existing emission tests carried out in some I/M programs. However, in several more recently implemented and proposed programs anti-tampering (ATP) checking and testing would constitute the inspection part of the whole program.

The primary reasons for an ATP program are the recognition that an idle short test of exhaust emissions does not measure NO_x and evaporative HCs, and that excess tail-pipe emissions occur only because of tampering and misfueling, besides normal deterioration due to vehicle aging. As mentioned in an earlier section various survey data[56, 81, 100] have indicated also that the higher idle emissions of tampered vehicles are due partly to the result of tampering itself and in part to the fact that tampered vehicles tend to be malfunctioning, maladjusted and/or misfuled as well. Therefore, an ATP program usually consists of inspection for maladjustment of emission-related engine components, and of checking of fuel inlet restrictor as well as a test for lead in the tailpipe of vehicles equipped with catalytic converters, besides inspection for tampering with other emission control devices and related accessories. Malfunctioning devices, due to improper maintenance, may also be detectable in a tampering inspection[100].

There are several different varieties of similar emission control devices which can vary from manufacturer to manufacturer, as well as from model year to model year. A list of various components which should be included in a comprehensive ATP program is provided in Table 4.2. Depending on the objective of the program, whether to reduce CO, THC or NO_x emission, an agency may select the components to be inspected in various model year vehicles.

Apart from the testing for lead in the vehicle tailpipe, tampering checks could be performed by visual inspection or functional tests. The EPA in the U.S.A. requires that all manufacturers affix a permanent legible label in a readily visible position in the engine compartment with information on tuning specifications and a list of emission control systems[82].

The visual inspection is usually carried out by opening the vehicle's hood to check the existence and condition of various emission control systems and other devices as necessary. In a functional test various methods, including engine idling, are employed to see whether specific components are operational. An agency should take precautionary measures against any potential liability problems arising from any damage to the vehicle component during functional test[105].

The test for misfueling is carried out by using a lead sensitive paper, capable of determining the presence of lead, against the inside surface of the vehicle's tailpipe for a few seconds. "Plumbtesmo" is the trade name of a lead sensitive test paper which is commonly used for this purpose, and the EPA has a recommended procedure[106, 107] for its use. The results from Harris County, Texas ATP program and other studies indicate that the Plumbtesmo test method is a valid and reliable one to identify misfueled vehicles in an inspection program[107, 108].

The pass/fail criteria used in the ATP programs are based on the observation of any maladjusted or tampered emission control related components and accessories.

6.1.3 Vehicle Exemptions

Amongst the I/M programs[98] in the U.S.A. only one program does not exclude any type of vehicle from inspection, as shown in Table 5.5. Motorcycles and diesel vehicles are exempted in most programs. A few of the programs exclude vehicles using fuels other than gasoline. In most programs light-duty trucks are inspected along with passenger vehicles; however, the inspection of other types of vehicles is limited to an upper limit of gross vehicle weight which varies from program to program. Heavy-duty vehicles are exempted from inspection in most cases.

The other criterion for exemption of vehicles from an inspection is the age of the vehicle. Vehicles of all ages are included in eight of the programs in the U.S.A., while in others there are varying exemptions based on vehicle model years.

It appears that an agency must consider several factors before deciding on the types of vehicles to be exempted from an I/M program. Obviously a program would be most effective, in terms of reduction of emissions, if no vehicles are exempted from inspection. However, for practical reasons site-specific relevant factors, such as the composition of the local fleet, information on tampering and misfueling, the program cost, etc., are weighed against the overall program objective in terms of air quality benefit desired.

As the primary objective of an I/M program is to screen out the worst of the gross emitting vehicles, an agency is usually faced with the dilemma in selecting the cut-off points for vehicle exemptions in terms of both vehicle type and age. A survey of the local fleet is essential in this respect. Light duty trucks, because of their similarities with the automobiles as far as emission control technology and emission standards are concerned, are relatively easy to include in an I/M program. For other types of vehicles additional program elements, such as emission standards, stringency factor, inspection methods, etc., have to be established.

All new vehicles are inspected in an I/M program, despite the fact that they are less prone to be gross emitters. By including these vehicles the owners are encouraged to maintain them properly, and also any repair costs resulting from component failures are covered by the warranty. The vehicles equipped with new emission control technology may become extremely high emitters, if they are tampered, misfueled and/or have component failure[52, 55, 56, 100, 109]. Although the older vehicles are known to be gross emitters, because of deterioration and higher rate of tampering, their inclusion in an I/M program does not always increase the overall effectiveness of the program[56, 100]. Studies by EPA have shown a negligible effect on I/M effectiveness in terms of emission reduction of exempting pre-1968 MY vehicles[100].

Older vehicles are also equipped with emission control systems with a variety of different components. A growing number of small components, hoses, valves, etc. are becoming unavailable in the market. Because of the above reason as well as of the mileage contribution of older vehicles of the fleet, the Department of Environmental Quality in Oregon is considering exemption of 1974 and older model year vehicles from underhood inspection[82].

It appears that the selection of vehicles for exemption from an I/M program should be made after due consideration to various factors mentioned above. The selection should be made above all according to a matrix of the fleet composition based on model year, mileage accumulation and emission control technology mix.

6.1.4 Inspection Facilities

There are three basic categories of vehicle inspection facilities: centralized, decentralized and "hybrid". In centralized programs the vehicles are inspected in facilities designed for high-volume testing only, but the necessary repairs are carried out elsewhere. These facilities are run either by the agency responsible for the program, or by a contractor, or by a number of licensed private companies. Decentralized programs generally involve existing repair facilities which have been licensed by the implementing agency to conduct vehicle inspection and reinspection. Both types of programs have certain advantages and disadvantages, as listed in Table 6.4.

A "hybrid" program combines the advantages of centralized and decentralized facilities to suit the local needs. Besides the Washington, D.C. area the State of New Jersey has the only "hybrid" program in the U.S.A.[98]. There all initial inspection of vehicles are carried out at state-operated centralized facilities. However, the owners of the failed vehicles have the option of either coming back to the same facilities for reinspection, or having the reinspection done at one of the licensed repair facilities[55]. As the Washington, D.C. area is under more than one control agency, the overall program consists of both centralized and decentralized features implemented by different agencies[49, 84].

The choice of the type and number of inspection facilities depends not only on the overall I/M program effectiveness desired, but also on the existing conditions in the program area. For example, if there are already facilities for vehicle safety inspection in the area, the agency is likely to consider adding emission inspection to the system from the standpoint of initial cost and administration. In such cases

TABLE 6.4

Centralized and Decentralized Facilities - Certain Advantages and Disadvantages

Centralized

Advantages

- efficient agency control over the entire inspection program
- potential for lower inspection costs because of high volume test facilities
- relatively easy to check inspector performance
- public confidence is more as the facilities are not connected with repair industry
- data collection, handling and analysis are relatively easy, and data quality assurance is better
- computerized data management is easier with less number of facilities

Disadvantages

- unless grafted to an existing safety inspection system, initial capital cost is more and may delay the program implementation
- public inconvenience in general due to smaller number of inspection facilities
- no involvement of private sector at large even if the inspection is carried out by a contractor

Agency Operated

Advantages

- potential for fraud is less
- standardized inspector training and test equipment
- potential for more unbiased inspection
- more control over the program
- reportedly less costly than contractor operated

Disadvantages

- potential public sector backlash
- more subject to short term program changes, but decision making process may be long because of red tape

Contractor Operated

Advantages

- the implementing agency is not involved in day-to-day operation
- the agency can put more emphasis on audit, data analysis and management
- easier control over inspector training, test equipment, etc. than in a decentralized program
- less potential for bias with respect to repair recommendations

Disadvantages

- potential for fraud exists, especially with a sticker enforcement system and inspection accountability
- renegotiation is necessary for any changes in the contract
- program dependency on a single contractor

Decentralized

Advantages

- a large number of private garages could be involved
- initial capital cost is less
- less inconvenience to public to have their vehicle inspected, and quite often the repairs are carried out at the same location
- there is more flexibility towards any program changes of minor nature
- the program could be reduced in size as necessary without causing much inconvenience

Disadvantages

- each facility must have test equipment, trained inspectors and data handling system
- agency faces unique problem of data collection because of the large number of stations and inspectors
- agency requires more manpower to adequately monitor the performance of each facility, regardless of the inspectors themselves
- potential problem of developing and maintaining a high level of quality control because of the number of facilities
- negative motivational factors such as low financial reward and individual biases could reduce program effectiveness
- problem of inspector training and experience
- credibility problem because the garages may be perceived by the vehicle owners to have failed the vehicle to get the repair business

the decision regarding centralized or decentralized inspection facilities becomes irrelevant. If the safety inspections are carried out at privately licensed service facilities, and these are also authorized to perform emission inspections, the program automatically becomes decentralized. Only decisions remaining to be made are the cost of any additional equipment, quality assurance and enforcement.

When an agency has to design an I/M program from the beginning, the area to be covered, the type of inspection and the estimated vehicle volume become the major determinant for the type of inspection facility necessary. In an area with a large vehicle population, centralized facilities are reportedly more attractive and the design of an efficient vehicle inspection procedure becomes more important than say inspection equipment costs[55].

However, other important factors, such as inspection time and waiting period and any inconvenience to vehicle owners, need also to be considered prior to a final decision on this feature. The type of program to be implemented determines to a large extent the time necessary to carry out the inspection. The inspection time could be reduced by allocating sufficient facilities and inspectors, which would undoubtedly add to the program cost. On ther other hand too long an inspection time and a waiting period would be inconvenient to the public. Similarly, a limited number of inspection stations in a large area with a fair size of vehicle fleet would cause public inconvenience. These factors and other specific to a particular area should also be considered in making a final decision on the type of inspection facilities.

It is apparent from a review of the available information[55, 97, 100] on various I/M programs in the U.S.A. that the final choice of an inspection facility is often based on socio-political reasons rather than on technical merits. A centralized, agency-operated facility seems to be the most flexible and cost-effective program in terms of quality of inspection provided and control over the program. It has been reported[97, 100, 104] that decentralized programs have the potential for generating variable and suspect test results. Moreover, as vehicle inspection, reinspection and rapairs are all carried out usually at the same facility, fraudulent practices by inspectors/mechanics can not be ruled out. To overcome these negative factors, the program implementing agency must establish a strong enforcement and quality control program.

6.1.5 Frequency of Inspection

An agency implementing an I/M program has to decide how often the designated vehicles should be inspected. It appears that there are four options available to the decision-makers as outlined below. Each option has its advantages and disadvantages, and the major determinant factors are the vehicle population, the type and number of inspection facilities, the nature of inspection, the available resources, and the cost and inconvenience to the vehicle owners. As mentioned earlier in almost all the I/M programs in the U.S.A. vehicles are inspected annually, while biennial inspection is carried out in three jurisdictions[98].

6.1.5.1 Annual Inspection

Since most vehicle licensing agencies require annual renewal of vehicle registration it would be relatively easy to administer a system for an annual emission inspection of vehicles, although this would cause some additional work for the existing agency. Also if an I/M program is coupled with the annual safety inspection, the vehicle owners could easily have their vehicles tested for emissions at the same time. From the standpoint of I/M program objective of emission reduction, an annual inspection allows less time to the owners of high-emitting vehicles to continue driving the same vehicle before repairing and returning for reinspection.

6.1.5.2 Biennial Inspection

The only advantages of inspecting the vehicles every two years instead of annually are the smaller inspection facility requirement and the vehicle owners would be making less trips to the inspection facility. A recent analysis[110] has shown that a biennial program may be more cost-effective than an annual program, as inspection-related costs are 50% of what they would be in an identical annual program.

However, because of the time lag between the inspections, the vehicles with emission levels just below the cut-points may well become gross emitters long before their reinspection as a result of deterioration and/or tampering. There may also be some confusion among the public and agency staff, at least during the initial stages of the program implementation, especially if the area already has an annual vehicle registration system.

6.1.5.3 Registration or Change-of-Ownership Inspection

The number of new vehicles registered and that of older vehicles changing hands vary from area to area, but the total number of such vehicles usually constitutes a small portion of a fleet in an urban area. The small number of vehicles to be inspected in this type of program would necessitate other elements of the program to be correspondingly smaller than programs with annual or biennial frequencies. One potential advantage of this method of inspection appears to be that the older vehicles, which are commonly resold, would constitute a large fraction of the vehicles to be inspected, and the older vehicles are usually the gross emitters. However, this advantage may be nullified if there are regulations in the area prohibiting the sale of vehicles with maladjusted or disabled emission control systems.

The major disadvantage of this inspection frequency is that a large number of in-use vehicles will not be inspected, and consequently, the overall cost-effectiveness of emission reductions through an I/M program is likely to be very low. Moreover, the whole program will be less deterrent to tampering, as vehicle owners cannot be expected to repair previous tampering until the time of resale or inspection.

6.1.5.4 Random Inspection

A random inspection or "spot check" involves inspection of some percentage of the areawide vehicles at the desired frequency, chosen from all vehicles in operation. There are at least two means of carrying out such inspection[56]. The most common way is to select vehicles while operating on the road and pull them over to the roadside, with the aid of a law enforcement officer, for inspection at random. Another approach may use the vehicle registration system to pre-select vehicles for inspection and to advise the respective owners of the intended inspection of their vehicles at a designated facililty within a specified period.

The advantages of a roadside inspection of randomly selected vehicles is that no expensive test facility is necessary and it could be implemented quickly. There are several disadvantages of this method of inspection. The vehicle selection process is liable to be biased, and the vehicles chosen may not reflect the desired fleet population. A large number of vehicles may be required to achieve any significant emission reductions. For the purpose of reinspection, fixed inspection facilities would also be required. However, the major disadvantages of this approach are that inspections may be at times which will often be inconvenient to vehicle owners, adverse weather can prevent the desired number of inspected vehicles, and that alert drivers can often avoid the inspection trap.

Through the pre-selection of vehicles by registration method it is possible to achieve true randomness in selection as well as the vehicles by model year desired. This method also causes little inconvenience to the selected vehicle owners, as they can take their vehicles to the inspection facility at their convenience. The major disadvantage is that as a vehicle will not be inspected at a regular frequency, the owner may not maintain the vehicle properly after passing the inspection and may also take a chance of not being called again for another inspection and proceed with tampering and misfueling. Although a random inspection may be less costly, its deterrence value appears to be much less than inspections carried out at regular intervals.

6.1.6 Inspection Fee

One of the direct and immediate cost to the vehicle owners resulting from implementation of an I/M program is the vehicle inspection fee charged by the regulatory agency. Inspection fees in currently operating programs in the U.S.A. range from none to $50 (US) in Anchorage, Alaska, the usual range, however, in most programs is $5 to $10 (US). While there are no reinspection fees in the majority of the programs, some do charge such fee for vehicles which fail the initial test and return after undergoing repairs.

The inspection fee is a non-technical issue, and is often decided after consideration of local issues. There are, however, certain cost-associated elements of an I/M program which influence the decision on charging an inspection fee. Major considerations appear to be the type of inspection to be performed, the facility type, the number of facilities for the designed number of vehicles to be tested, the time necessary for an inspection, local labour cost, and other similar cost-related program elements. The foremost of all is whether the program should be self-sufficient in terms of overall cost, or be subsidized by the government, or become a source of revenue.

6.1.7 Repair Costs and Waiver

The cost of repairing a vehicle which fails an I/M inspection test is entirely a site-specific matter and depends primarily on the local costs of parts and labour. However, certain features of the program determine the extent and type of repairs, necessary for a failed vehicle to pass the retest, which in turn reflects on the cost of repair. The most important ones are the vehicle type, the kind of test employed, emission cutpoints, if applicable, and the stringency factor. Other factors which also have a bearing on the repair cost are mechanic training and the degree of enforcement of the program.

There are various repair cost figures incurred in several I/M jurisdictions in the U.S.A. available in the literature[52,55,84,85,99,100,104,111]. However, such information does not appear to be of any specific value to an agency designing an I/M program, unless the details of repairs carried out and the associated parts and labour costs are also available at the same time. The average repair costs cited in the available literature are summarized in Table 6.5, just for the sake of information only. Because no attempt has been made here to normalize the data from various sources because of the inherent variabilities amongst the I/M program characteristics, the method of estimating the average cost, and three important features of an I/M program, namely the cost associated with the tampered devices, the repair cost ceiling, and the training of mechanics.

In many I/M programs, when a vehicle fails an inspection test, it is a common practice to grant the vehicle owner a waiver from obtaining additional repairs which are above a set repair cost ceiling. Such waivers vary from $15 to $300 (US) amongst the existing programs in the U.S.A., although some programs do not have any cost waiver and almost non allows any waiver for repair costs associated with tampered emission control components. This program feature and its impact on the program effectiveness will be discussed later.

The experience of EPA and other agencies in the U.S.A. involved in I/M programs indicates that the cost of repair of vehicles can be reduced by proper training of mechanism in the automobile service facilities. As mechanic training is regarded as one of the major features of an I/M program, this aspect is dealt with in another section.

The average repair costs shown in Table 6.5 can be misleading as they can be skewed heavily by a few disproportionately high or low values in the sample of vehicles analyzed. This is evident from Figure 6.1, based on EPA's analysis of the distribution of repair costs for 1972-1977 model year vehicles which failed in the Portland, Oregon I/M program[83]. The detailed analysis of these data by EPA has indicated that

TABLE 6.5

Average Vehicle Repair Costs to Pass I/M Program

Vehicle Model Year/Type	Average Repair Costs ($US (Year))	Source
Pre-1981 Vehicles[1]	17-30 (N/A)	-
1980 & 1981 Vehicles[2]	Approx.95 (1984)	-
1981, 1982, 1983 & 1984 Vehicles[3]:		-
- All	110 (1985)	
- Carbureted	120 (1985)	
- Fuel Injected	68 (1985)	

[1] The data from several I/M programs. No details on vehicle numbers and types are available.

[2] 78 vehicles - 24 1980 MY and 54 1981 MY (13 carbureted open-loop, 35 carbureted closed-loop and 6 fuel injected).

[3] 100 vehicles - 38 1981 MY (8 carbureted open-loop, 28 carbureted closed-loop and 2 fuel injected), 29 1982 MY (12 carbureted open-loop, 14 carbureted closed loop and 3 fuel injected), 18 1983 MY (carbureted open loop, 2 carbureted closed loop and 10 fuel injected), and 15 1984 MY (6 carbureted open loop, 5 carbureted closed loop and 4 fuel injected).

N/A Not available.

Source: 52, 84, 85, 100

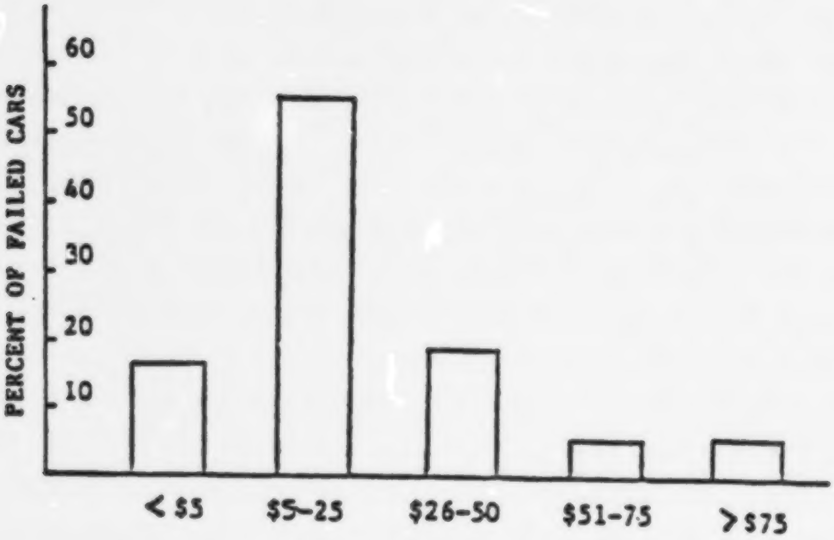


FIGURE 6.1: Distribution of Repair Costs for Failed Vehicles in EPA's Portland Program Study (1972 - 1977 MY Vehicles)

Source: 52

while 50% of the sampled vehicles had repairs costing $14 (US) or less, the average cost rose to $29 (US) because of high repair costs associated with a small number of vehicles in the sample.

With the advent of the new technology vehicles based on electronics and various sensors, the repair of failed vehicles is expected to rely mainly on correct system diagnosis followed by component repair or replacement. Therefore, instead of an adjustment nature of repairs usually performed on older model vehicles, the trend in the repairs of new emission control components appears to be much more of an "all-or-none" issue[85, 112]. The replacement costs of catalysts and oxygen sensors are reportedly high. The average repair costs of the post-1980 MY vehicles reported for the Washington, D.C. and Maryland I/M areas, as shown in Table 6.5, tend to confirm the above observations.

Landman[85] has carried out the repair cost analysis for the Maryland area in more detail, as shown in Table 6.6. In his analysis he took into account only the time actually spent on repair work by the mechanic and the average cost of the replacement parts that were needed. The time spent by the mechanic on inspection or diagnostic work was not included, and a fixed labour cost of $30 (US) was assumed. According to Landman[85] the mean values shown in Table 6.6 can be misleading since they are skewed by a few disproportionately high values. For example, of the 49 closed-loop, carbureted vehicles, 6 vehicles needed at least $275 (US) each to repair, and 5 of those 6 vehicles required new ECMs as well as possibly other repairs. The sixth vehicle needed extensive repairs including catalyst replacement. The repair costs for those vehicles which received a new ECM or a new catalyst ranged from $275 (US) to $900 (US).

TABLE 6.6

Distribution of Repair Costs by Repair Parts, Repair Time, and Estimated Total Cost of Vehicles Failing in Maryland I/M Program

Distribution of Repair Parts (in dollars)

Vehicle Type and Number		Percentile															
Type	No.	5%	10%	20%	25%	30%	1/3	40%	50%	60%	2/3	70%	75%	80%	90%	95%	99.9%
All Vehicles	100	0	0	0	0	0	0	0	10	30	35	40	70	100	260	390	600
Carbureted	81	0	0	0	0	0	0	0	0	12	35	37	80	130	275	410	600
Fuel injected	19	0	0	0	0	10	30	30	35	35	40	44	45	100	125	150	150
Closed-loop	68	0	0	0	0	0	0	0	30	35	50	80	100	150	330	420	600
Open-loop	32	0	0	0	0	0	0	0	0	8	10	10	10	15	95	140	250
Closed-loop carbureted	49	0	0	0	0	0	0	0	12	37	80	90	150	265	410	450	600

Distribution of Repair Time (in hours:minutes)

Vehicle Type and Number		Percentile															
Type	No.	5%	10%	20%	25%	30%	1/	40%	50%	60%	2/3	70%	75%	80%	90%	95%	99.9%
All Vehicles	100	0:20	0:30	0:30	0:30	0:30	0:30	1:00	1:00	1:00	1:15	1:30	1:30	2:00	2:00	3:00	15:00
Carbureted	81	0:20	0:30	0:30	0:30	0:30	0:30	1:00	1:00	1:15	1:30	1:30	2:00	2:00	2:30	3:00	15:00
Fuel injected	19	0:20	0:30	0:30	0:30	0:30	0:30	0:30	0:30	1:00	1:00	1:00	1:00	1:00	2:00	2:00	2:00
Closed-loop	68	0:30	0:30	0:30	0:30	0:30	0:30	1:00	1:00	1:00	1:15	1:30	2:00	2:00	3:00	4:00	15:00
Open-loop	32	0:10	0:15	0:30	0:30	0:30	0:30	0:30	1:00	1:00	1:30	1:30	1:30	1:30	2:00	2:00	2:00
Closed-loop carbureted	49	0:30	0:30	0:30	0:30	0:30	1:00	1:00	1:00	1:30	1:30	2:00	2:00	2:00	3:00	6:00	15:00

Distribution of Total (estimated) Repair Cost (in dollars)

Vehicle Type and Number		Percentile															
Type	No.	5%	10%	20%	25%	30%	1/3	40%	50%	60%	2/3	70%	75%	80%	90%	95%	99.9%
All Vehicles	100	15	15	15	15	29	30	30	43	57	65	74	120	160	305	465	900
Carbureted	81	15	15	15	15	29	30	30	38	55	70	90	130	190	365	495	900
Fuel injected	19	15	15	15	25	30	45	50	60	60	60	70	74	135	165	185	185
Closed-loop	68	15	15	15	25	30	30	38	50	65	110	130	160	210	420	590	900
Open-loop	32	5	8	15	15	15	15	30	30	45	55	55	57	60	140	195	280
Closed-loop carbureted	49	15	15	15	29	30	30	30	42	90	130	185	210	325	495	610	900

Source: 85

Several general observations have been made from the investigations referred to above. The significant among those are that older vehicles, which are more prone to fail during I/M inspections, require more repairs in general, and so incur higher repair costs. However, the nature of repairs necessary is usually of adjustments type, and any replacement of emission control related components is relatively less expensive. The recent model year vehicles equipped with electronic control modules, sensors and catalytic converters may need less repair, but when it becomes necessary, the overall repair cost is usually quite high because of the replacement of certain components.

6.1.7.1 Waivers

In many I/M programs in the U.S.A. a vehicle owner is granted a waiver from obtaining repairs done to the failed vehicle which are above a set repair cost ceiling. Such waivers are, however, not allowed with respect to repairs on tampered components in most programs. The primary reason behind allowing cost waivers towards vehicle repairs appear to be non-technical, as it affects the program effectiveness with respect to emission reduction. The system is used to ease the burden of vehicle owners from footing the entire, and often expensive, bill for repairs essential to pass the inspection test.

Ideally, for a program to be effective, all necessary repairs to a failed vehicle should be performed, irrespective of the cost involved, and the repaired vehicle should pass the retest. If a waiver system were to be used, it should then be sufficiently high to cover most of the essential repairs. A low repair cost ceiling undercuts the program effectiveness significantly.

In the state of Alaska, where the highest repair cost waiver is granted, because of its unique repair service industry, the agency specifies the repair procedures for vehicles failing the I/M inspection test to ensure that repairs are pursued in a logical manner[99]. The Alaska programs also allow a cost ceiling for the most common forms of tampering up to $500 (US) when the programs are implemented fully[99]. As mentioned earlier, most programs have no waiver for repairs done to correct tampered components.

Waiver rates may vary according to vehicle model years or emission cutpoints, depending mostly on the repair or component replacement and local labour costs. The system appears to have certain inherent deficiencies which could lead to abuses and exploitation by the repair service industry. In general, a large number of failed vehicles receiving waivers tends to indicate that there are problems within the repair service sector and that vehicles are probably having unnecessary or improper repairs done to them. A high waiver rate may also indicate that there are some illegitimate waivers. On the other hand, a low waiver rate may suggest inadequate inspections are being performed.

EPA auditors[97] have found that the number of waivers granted vary from program to program, and also to some extent with the type of the program. In programs where the implementing agency processes waiver applications, the problem appears to be due to the lack of adherence to any strict processing procedure. Waiver rates seem to be especially high in decentralized programs where waiver applications are not processed by the agencies.

The above auditing as well as other recent investigations[84, 85] by EPA have led to a belief that the use of relatively low waiver cost ceilings is somewhat lowering the program effectiveness in terms of emissions reductions. Another reason for high waiver rate granting may be due to the higher costs of replacement components, such as catalysts and sensors, for recent model vehicles. This aspect of a program can be ignored if no waiver is allowed for any repair necessary to pass an inspection test be it emission, tampering or misfueling.

6.1.8 Enforcement

Apart from the computer-matching method used in a few programs, most I/M programs in the U.S.A. employ either a registration based or sticker system of compliance method. As the computer-matching is not so prevalent yet, not much information is available about its effectiveness.

It appears that no significant problems with registration based programs have been observed by EPA auditors[97]. However, there are potential drawbacks to this method of enforcement. Some of these are registration of uninspected vehicles due to clerical errors, failure by police officers to ticket vehicles for expired vehicle licence plates, and registration of vehicles by the owners outside the I/M program area to avoid inspection.

There is a greater possibility of noncompliance with a sticker enforcement system than with a registration system. The common problems encountered in sticker systems are the lack of police efforts to enforce sticker regulations, and the sticker accountability in some programs[97, 102]. Adequate legislations to authorize local police officers, availability of resources and co-operative attitudes on the part of the police force are essential for the program enforcement.

Sticker accounting for each inspection station and proper data management system, and regular auditing should be performed to eliminate the sticker accountability problem.

6.1.9 Mechanic Training

The quality of repairs performed on failed vehicles is an important aspect of an I/M program, as the success of the program depends on it. Two major yardsticks for the program success, emission reductions and the repair cost, hinge on this particular feature. If vehicles are reparied carefully, in accordance with the manufacturer's specifications, maximum emission reductions are achievable at a reasonable cost.

Increased effectiveness of I/M programs in which mechanic training is an essential feature has been reported[100, 104]. It has also been observed that in those programs fewer cases of vehicles continuing to fail the emission test cutpoints after repairs. However, recent investigations[84, 85] by EPA have also shown that some commercial repair facilities may not be competent, motivated or equipped to perform proper diagnosis and repair.

Like any other service industry, automobile repair industry is not perfect. As regards as I/M programs are concerned, some of the problems associated with vehicle repairing stem from a lack of knowledge in the industry of correct diagnosis and repair procedures for emission related components. In addition, the unscrupulous actions of the repair mechanics in certain cases are likely to affect the program effectiveness. The experience in the I/M programs indicates the possibility of the following problems arising due to the above factors:

- vehicles receiving unnecessary and expensive repairs and adjustments,

- replacement of good parts,
- improper adjustments and repairs requiring the vehicle owner to make more than one repair trip,
- encouraging the vehicle owner to attempt to acquire compliance without completing necessary repairs, and
- deliberate and incorrect failure of vehicles in the initial test in a decentralized program to acquire repair business.

These potential problems can be made less frequent, which would result in reduced repair cost and thus the program cost, by requiring proper training and licensing or registration of the mechanics in the repair service industry. Such a training course has been designed by the Colorado State University which provides the mechanics with the basics of diagnosis and repair for vehicles[104].

The vehicles of recent model years equipped with new emission control systems require particular attention by the mechanics for proper diagnosis and repair to correct any failures as well as to keep the cost down. The repair of these vehicles is expected to be largely of a component nature instead of an adjustment type. As a result, the repairs are likley to be an all-or-none issue, involving expensive component replacement[112]. Therefore, the correct system diagnosis prior to any repair would be an essential prerequisite, as incorrect diagnosis followed by incorrect repair would result in correspondingly high emissions and unnecessary repair cost to the vehicle owner.

As late-model vehicles are expected to have features like warning lights and on-board diagnostics which would display trouble codes for component failures, the repair mechanics should be proficient in these diagnosis systems. Recent investigations[85] on a limited number of vehicles have indicated that vehicles which displayed computer trouble codes had significantly higher THC and CO emissions than those vehicles of same make and failed an I/M emission test but did not display computer trouble codes.

EPA is convinced that mandatory training of mechanics in the repair service industry can result in increased program effectiveness[104, 112]. It also ensures that an adequate number of properly trained local mechanics would be able to handle the repairs necessary as a result of an I/M program in the area. Moreover, it also benefits the vehicle owners as the industry must provide competitively-based prices for such repairs.

6.1.10 Public Information Activities

To "sell the product" or, in other words, to implement a successful I/M program, a comprehensive public information and education program is essential, as it affects the public in more than one way. Such a program should be initiated once the decision is taken to introduce an I/M program in an area, and it should continue in modified forms throughout the planning, implementation and life of the program.

An understanding by the public, vehicle dealers, repair service industry, and other affected groups of the necessity for and operation of an I/M program is critical for its success. During the planning stage an extensive public information program should be designed to both raise the level of understanding of air quality/motor vehicle issues in the area. The program should preferably allow public participation and provide adequate opportunities for the area citizens to participate in the planning process.

To accomplish these goals, emphasis should be given to disseminating relevant information explaining the characteristics of the area's air quality problem, how air pollution affects area residents and what is being done to improve air quality. Through this program, the repair service industry should also be addressed to in appropriate ways explaining the importance of its role. The vehicle owners should also be made aware of the availability of licensed mechanic facilities in their particular areas.

After the program implementation, current operating information should be provided to the public on an on-going basis. During each phase of the program an evaluation of public awareness about the program should be carried out by opinion polls.

These activities may be conducted by the implementing agency or by contract to a public relations firm. In any event, there must be a comprehensive plan and adequate budget for the whole program. The plan should consist of the use of television, radio and print media, special seminars for the public as well as for repair mechanics, special promotional events or demonstrations, voluntary phase-in period inspections, if any, handling of complaints or enquiries from the public, and operation of a telephone "hotline".

6.1.11 Program Evaluation

Like many other systems an I/M program depends on feedback for an assessment of how it is actually operating. Various data from different program elements provide the feedback; hence, accurate data collection and analysis on a regular basis are essential for the determination of program effectiveness. Such periodic evaluation of the program is also necessary to redesign any program element to enhance the effectiveness in terms of emission reductions.

Because of the number of elements involved, an I/M program could generate a large quantity of data. It is therefore necessary to establish a data collection and handling system, as well as to identify key data sets and develop analytical techniques. The role of the implementing agency in operating a successful I/M program, particularly in a decentralized program, is critical, and adequate resources must be allocated for this purpose.

Auditing of inspection facilities, test procedures, data collection and recording systems by the agency personnel at regular intervals is essential. The design of fraud-resistant entry forms at inspection and repair facilities, and a computerized data management system should be considered for the purpose of quality assurance.

6.1.12 Program Cost and Cost Effectiveness

Considering the complex nature of the I/M program, involving several site-specific variables, it is impossible to estimate any reliable costs for implementing and operating such a program. The available information on such estimates for a few specific programs could be misleading without any detailed background knowledge of the program elements and the factors considered in deriving the program cost. For example, the cost will depend on the type of the program, inspection facilities, number of vehicles tested, pass/fail criteria, repair costs due to the program only, inspection fee, cost waiver, etc. Other factors which affect the cost of an I/M program are mostly indirect, nevertheless important, and depend on the social characteristics of the program area.

EPA has published several reports on cost estimation procedures for I/M programs which are useful references to carry out such tasks once the basic program design is completed. Palmini and Rossi[113] have carried out a comprehensive cost analysis for the I/M program in New Jersey. Although it is not wholly useful to other programs, the general approach of the study appears to be informative, as outlined below.

In a generic sense, the cost of an I/M program consists of that incurred by the implementing agency, the inspection facilities, the vehicle owners, and the repair service industry. However, the costs to the decentralized inspection facilities and repair service industry are recaptured by the implementing agency and the vehicle owners respectively through inspection fees and repair charges. Therefore, the total of program costs would be the total of costs to the implementing agency and the vehicle owners.

The direct costs incurred by an agency are capital and program start-up costs, and operating and maintenance costs. For the vehicle owners, there are "out-of-pocket expenses" as well as "opportunity costs". The potential benefits which may be accrued by the vehicle owners are: less need for major repair once the vehicle passes the I/M inspection/ reinspection and improved fuel economy.

Regarding the cost effectiveness of an I/M program, in terms of cost per unit of a contaminant emission reduction, with respect to other potential control measures is concerned, more detailed excercise is necessary to obtain a comparative picture. Again various site specific information is necessary to conduct such estimates. Recently, EPA has published a draft report[36] of a generic approach for the estimation of economic benefits of controlling HC and NO_x in non-attainment areas for O_3. However, these estimates are also based on some crude assumptions, and the authors were reluctant to draw firm conclusions.

6.2 I/M Program Effectiveness, Emission Reductions and Fuel Economy Benefits

As mentioned earlier the majority of the I/M programs in the U.S.A. are based on the conventional method of testing of exhaust emissions of in-use vehicles. It is only in recent years inspection of engine parameters and emission control systems as well as misfueling tests are becoming the primary features of an I/M program. Some of these latter type of inspection parameters have also been incorporated in several older conventional I/M programs recently to increase the program effectiveness.

I/M programs have been implemented in the U.S.A. as one of the measures to reduce emissions of carbon monoxide and hydrocarbons from motor vehicles, and thus to meet the national air quality standards of carbon monoxide and/or ozone in non-attainment areas. In this section the effectiveness of I/M programs in reducing vehicular emissions is discussed, and the impact on the air quality will be dealt with in a later section. It should also be noted that as the main objective of this report is to address the feasibility of an I/M program for the Lower Mainland area with an oxidant problem, the following discussion deals more with the potential reduction of hydrocarbon emissions than that of carbon monoxide. However, as mentioned earlier the mechanisms of CO and THC formation from motor vehicle engines and the technology usually employed to control exhaust emissions for both contaminants are very similar. Therefore, any reference to reduction of THC emission through the vehicle tailpipe generally implies that there will be a concomitant reduction in CO emission.

On reviewing the information available on the I/M programs in the U.S.A., there appears to be certain inherent difficulties in identifying the program deficiencies and ascertaining the extent of emission reduction potential. One of the major drawbacks appear to be the relative newness of this particular emission control measure which has not yet resulted in any comprehensive evaluation of I/M programs as a whole. The varied characteristics of different program elements do make it difficult to compare the program deficiencies. In addition, the introduction of different emission control systems, in response to promulgation of stricter emission standards and regulations in the U.S.A., during the last few years has also complicated to a certain extent the process of determining the emission reductions from a fleet of vehicles equipped with different emission control devices.

For the purpose of determining the effectiveness of I/M programs, simulation models[68, 69, 114] for emission factors have been developed by EPA during the last few years to predict current and future vehicle emission inventories for various regions in the country. The original model MOBILE 1 has been successively revised and updated to MOBILE 2 and MOBILE 3 versions, in recent years with current data. The key inputs to these models, such as emission data, vehicle model year and age, fleet composition, tampering and misfueling rates, etc., have been based on various programs[115-118] related to emission factor development. It has been reported that further refinement of MOBILE 3 model is presently being carried out based on new information[110].

Besides the estimated emission factors, there are various other factors which influence the overall I/M control effectiveness. However, most of these factors can be varied in the local program design, and have already been discussed in the previous sections. It has been suggested that in general the factors which are independent of local design, such as emission deterioration rate, are more sensitive to I/M program effectiveness than the local design factor options[55].

6.2.1 I/M Program Deficiencies

Within the general limitations outlined above, Austin and Husson[99] has compared the deficiencies of the major features of various I/M programs in the U.S.A. The features compared are considered essential for an I/M program with potential for being the most effective. On this basis the investigators have concluded that the I/M program in Portland, Oregon has all of the features, as listed in Table 6.7, and no significant deficiencies relative to other programs. It should be noted that the above comparison has been primarily based on the conventional I/M program features involving exhaust emission testing with visual anti-tampering check. However, the actual level of enforcement efforts in the programs has not been considered.

In 1984 the EPA started to audit the I/M programs and found several deficiencies in different programs involving emission short tests[97]. The findings of the audits indicate that:

- in many decentralized programs, particularly those using mannual emission analysers, and in some centralized, agency run programs have a problem of low reported failure rates;
- the emission analyser quality assurance varies from marginal in decentralized programs with manual analysers and in a few centralized agency operated programs to excellent in centralized, contractor run programs;
- several programs, decentralized as well as centralized, have a problem of high waiver rates;

TABLE 6.7

Suggested I/M Program Features for Maximum Program Effectiveness

- Stringent exhaust emission standards or cutpoints for short emission tests
- Proper procedures and equipment for emission testing and analysis; adequate performance and quality assurance of inspection tests
- Visual and/or functional inspections of emission control systems
- A data collection mechanism or reinspection requirement to ensure that inspections and repairs are performed properly
- Sufficient repair cost ceilings and repair requirement procedures to ensure that most failed vehicles are repaired completely
- Strict control on granting of waivers - repairs must be performed by certified mechanics by following approved procedures
- Effective compliance system to ensure vehicles are inspected and passed the program tests
- Adequate inspection fees to cover the cost of proper inspection unless subsidized otherwise

Source: 99

- some sticker based programs have inadequate enforcement;
- ineffective methods of data analysis are used in most programs to monitor and improve the performance of individual inspection facilities as well as that of the whole program; and
- in every program audited the quality of repairs done as a result of inspection is a problem to a certain extent.

Amongst the above deficiencies obsereved by EPA, the major technical item is the low failure rate as determined by the emission test, which is also a key element in determining the effectiveness of an I/M program in reducing vehicular emissions. Other deficiencies are either semi-technical or administrative in nature, and can be improved without affecting the purely technical aspect of the program. For example, replacement of manual analysers by recent automated analysers, improved data management system, proper training of mechanics, stricter enforcement method, and revised cost waiver method can resolve these problems and enhance program effectiveness.

Recent investigations[84, 85] by EPA have shown that repair costs for vehicles equipped with post-1981 emission control technology are higher than waiver limits in many I/M programs. It has been reported[84, 105] that EPA is now considering a requirement for higher repair cost waivers in those programs to improve their potential for emission reductions.

6.2.1.1 Effectiveness of Emission Tests and Anti-Tampering Tests

The short tests used in exhaust emission measurements have been the major item of controversy between industry and government, as far as its effectiveness in identifying vehicles with excess emissions is concerned, but more particularly in diagnosing the control system component defects[55]. The simple idle test, which has been in use in most I/M programs, is not designed to detect specific component disablement[56]. With the advent of the catalytic converters in 1975 and that of three-way catalytic converters, secondary air and fuel injection systems, as well as increasing use of microprocessor-based control devices since 1981, the ineffectiveness of short tests have become more apparent.

During the 1984 survey of tampering and misfueling rates in the U.S.A. it was observed that while 60% of the tampered and misfueled vehicles failed an idle test, about 10% of the survey vehicles free of any tampering and misfueling also failed that test[81]. It was also found that nearly 67% of the vehicles with missing or inoperative catalysts were still able to pass an idle test.

Further analysis of the data from the above survey[81] has indicated that the idle CO emissions from untampered and properly fueled vehicles which passed the test were not affected by I/M programs. The idle THC emissions from similar vehicles in I/M areas were found to be only 8% lower than from vehicles in non-I/M areas. The idle test emissions data from areas with I/M only and I/M + ATP program did not indicate any definite trend.

In conventional I/M programs it is usual for the failed vehicles to have only sufficient repairs done to pass the retest; it is not necessary to undergo complete repair job on all disabled or maladjusted components. Depending on the type of emission test employed, its error of commission, emission cutpoints and stringency factor used in a particular program, the exhaust emissions from a passed vehicle after retest may well be in excess of what could have been achieved after a complete repair job. In a recent investigation[85] involving 9 vehicles of 1981-1984 MY from the Maryland I/M program, it has been observed that additional reduction in emissions from some vehicles can be achieved by further repair of the retested and passed vehicles. The Maryland program has provisions for an idle test, a repair cost waiver of $50, and anti-tampering check of catalysts and fuel inlet restrictor during change of ownership only. The results from the above investigation showed that further reductions in emissions of THC and CO ranged from 0%-50% and 0%-60% respectively after additional repairs were done. Three vehicles showed emission reduction benefits of 34%-50% for THC and 53%-60% for CO. None of the vehicles showed any additional reduction in NO_x emissions as measured by FTP.

In an apparent attempt to defend the effectivensss of short emission tests in identifying gross emitting vehicles, EPA has recommended preconditioning of vehicles prior to actual idle test or the use of two-speed idle or loaded mode short tests as well as short test emission standards, as discussed in an earlier section. Several recent investigations[55, 82, 103, 119, 120] have shown that short emission tests by themselves are not entirely effective in identifying excess emitters or diagnosing malperforming emission control systems of new technology vehicles. Various tampering and misfueling surveys and studies on their impacts on vehicular emissions have led EPA to encourage state agencies to implement at least some tampering and misfueling checks along with the existing emission test[56, 100]. In Portland Oregon I/M program mandatory compliance with an underhood visual inspection of emission control systems was added in 1977 after two years of emission testing only[82]. Since then the whole program has resulted in significant emission reduction benefits for both THC and CO[82]. The value of tampering inspection has recently been recognized by the agencies as several other I/M programs have adopted it, and EPA is awarding SIP credit in I/M benefit estimation[82, 110].

In view of the problem of oxidants level in the Lower Mainland it is considered appropriate to discuss in particular the effectiveness of the conventional I/M program, involving a short emission test, in reducing emissions of major ozone precursors, namely reactive hydrocarbons and nitrogen oxides. In this respect the major drawback of exhaust emission test is that none of the reactive hydrocarbons emitted from evaporative sources in a vehicle is measured. The short idle tests are unable to measure NO_x emissions; only the loaded test is able to do that, but as mentioned earlier none of the existing programs in the U.S.A. measure NO_x emissions as a routine.

Exhaust emission tests in idle mode, 2-speed idle mode or loaded mode do not detect the presence of lead in the tailpipe discharge. Therefore, such tests are unable to provide any direct proof of misfueling which is reportedly one of the major causes of excess emissions from the catalytic converter equipped vehicles.

Considering that evaporative hydrocarbons emissions constitutes between 33% and 50% of the total hydrocarbons emission from a vehicle and that approximately 10-11% of the exhaust hydrocarbons is non-reactive[51, 70], it is estimated that about 40 to 45% of the reactive hydrocarbons emission from a vehicle would escape undetected by an emission short test. This estimation is for a carbureted vehicle and on the assumption that the PCV is untampered. The situation would be different if PCV is tampered or in the case of a fuel-injected vehicle.

After a review of several independent reports, Elston[55] has concluded that conventional I/M programs are probably less effective in reducing THC than CO and that hydrocarbon related malperformances are more varied and difficult to correct. He has also suggested that an I/M program design must consider post-1981 control technology penetration in the fleet, and should include an emphasis on detection and identification tests for emission control system malperformance and tampering.

The relative inportance of an anti-tampering program, instead of the conventional I/M program, to reduce vehicular emissions is becoming obvious especially in areas with ozone non-attainment problem. After a detailed investigation, including a pilot program of emission testing, the Texas Air Control Board implemented the first I/M program in the U.S.A. without an emission short test in July 1984 on approval from EPA[120]. The program in the Harris County is designed specifically to address hydrocarbon emissions from light duty vehicles, including trucks, equipped with new emission control technology, and to reduce the incidence of tampering and misfueling as well as to improve the quality of maintenance on vehicles, in particular of 1980 and later model years[119]. It is a decentralized program and besides visual and limited functional checks of emission control systems it also includes Plumbtesmo test for lead in the exhaust pipe. No information on the effectiveness of this particular program is available yet.

As mentioned earlier, since the approval of the Harris County I/M program EPA has also given approval to six more programs based on anti-tampering and misfueling inspections without any emission short test. There is no doubt that an ideal I/M program with both emission test and anti-tampering test should provide maximum emission reduction benefit. However, depending on the site-specific conditions, some areas could accrue similar benefit of hydrocarbon emission reduction by implementing either a conventional I/M program or one based on tampering and misfueling inspection. It has been reported [89] that preliminary appraisal by EPA indicates that a latter type program would have a cost-effectiveness for THC and CO emission reductions that is competitive with the conventional program.

It should be noted, however, that an anti-tampering program has some potential drawbacks and requires careful design and planning[104]. The major ones are the time required for proper inspection, the diversity in the design and location of emission control devices in vehicles of different manufacturers, and the lack of an immediate direct proof of excess exhaust emissions caused by any tampered component.

6.2.2 Emission Reductions

The effectiveness of an I/M program in reducing emissions of contaminants emitted from motor vehicles depends on its specific features, but above all on the degree of its enforcement. As each program is designed for a particular area with some definite objectives of reducing emissions of THC, CO or NO_x or all by certain quantities, no generalized area-wide estimates of emission reductions have been done. Because of the variabilities involved, the estimation of emission reduction benefits for a given area involves complex calculations using a number of assumptions, as all necessary information may not be readily available from actual field tests or surveys. Simulation models, using computer programs, are generally used to estimate area-wide emission reduction benefits through I/M programs[69].

In the following sections the available information on the effects of engine parameter maladjustment, tampering of specific emission control components, and of misfueling on vehicular emissions is presented. It should be noted, however, that it is not easy to quantify such effects, as there are many varieties of similar emission control systems which also differs from manufacturer to manufacturer and from one model year to the next. The nature of emission from a vehicle is also dependent on the engine type and the overall state of tune. Moreover, there are several inter-dependent components in particular emission control systems in a vehicle. Consequently, most of the data in the literature are based on laboratory test conditions instead of on-the-road tests. Some information on the impact of I/M programs on the overall reduction in emissions from vehicles in particular areas is also provided here as available.

6.2.2.1 Impact of Maladjustment

Several studies[55] with pre-1968 model year vehicles indicated that by simple tune-up, idle adjustments, ignition timing, and carburetor mixture adjustments resulted in improvements in CO and THC emissions. Depending on the type of adjustments made the average emission reduction ranged from 19% to 32% for CO and 9% to 48% for THC. It should be noted that different emission tests were used in these investigations, and none were standardized. An extensive investigation by the Coordinated Research Council using FTP emission test indicated that after maintenance by mechanics THC and CO emission reductions of only 10% and 7% respectively were observed for pre-1968 MY vehicles[55]. The same study also found emission reductions of about 4% for THC and 11% for CO after similar maintenance on 1968-1973 MY vehicles.

By correcting the idle mixture and idle speed to their proper settings on 1975-1976 MY vehicles, EPA studies[80] have observed average emission reduction of 68% and 23% for CO and THC respectively. During the testing of 1977 and 1979 MY vehicles by Environment Canada[76], the emissions of THC and CO improved by 10%-30% and 35%-55% respectively when the idle fuel/air mixtures were readjusted to the original specifications.

Although several field studies in I/M program areas have been carried out by EPA in recent years, the available information on emission reduction benefit due to restoration, repair or replacement of specific maladjusted or disabled components is limited. Such information from a recent study[85] in Maryland I/M program is shown in Table 6.8. The data are based on 101 vehicles of post-1981 MY that failed the Maryland I/M program idle test cutpoints (THC-220 ppm and CO-1.2%) and subsequently repaired. All vehicles were also subjected to FTP tests and emission reduction benefits associated with a single type of repair were determined by performing a linear regression analysis. It should be noted that some of the data shown in Table 6.8 are based on the repair types carried out on a small number of vehicles.

However, the results as shown in Table 6.8 do provide some general indications of the extent of emission reductions achievable through proper repairs. By resetting idle mixture only, the FTP emissions of THC and CO decreased by 34% and 54% respectively. The readjustment of idle speed alone reduced emission of THC by 37% and that of CO by 30%, while resetting of both idle mixture and idle speed resulted in decrease in THC and CO emissions of 44% and 61% respectively. Maximum emission reduction benefits of 93% for THC and 96% for CO were achieved by replacing the carburetor.

TABLE 6.8

Changes in Mean FTP Emissions Associated with a Single Type of Repair

Type and Number of System Repaired		Change in Mean FTP Emission (%)	
Type	Number	THC	CO
Induction (Air Filter)	1	42	38
Replace Carburetor	1	93	96
Fuel Metering:			
Reset idle speed	10	37	30
Reset idle mixture	15	34	46
Reset both idle speed and idle mixture	7	44	62
Reset idle speed and/ or idle mixture	32	37	46
Ignition System:			
Only spark plugs and/ or wires	2	36	10
Both distributor and spark plugs and/or wires	1	31	47
Either distributor or spark plugs and/or wires	3	35	30
EGR	2	+20	+12
AIR	6	33	50
PCV	1	76	72
3-Way Electronics:			
Sensors	14	75	86
PROM/ECM	3	30	54
Replace Catalyst	3	84	67

EGR - Exhaust gas recirculation
AIR - Air injection system
PCV - Positive crankcase ventilation
PROM - Program read only memory
ECM - Electronic control module

Source: 85

6.2.2.2 Impact of Tampering

Test results from various studies carried out by EPA[56] on the effect of tampering of specific emission control systems on the emission increases are summarized in Tables 6.9 and 6.10. These tests were, however, done with and without a particular emission control component disconnected. Usually the vehicles were in proper tune and all other emission control devices were in operation. It should be noted that the emission increases due to tampering of in-use vehicles may vary under less perfect condition.

The emission control devices listed in Tables 6.9 and 6.10 have been found to be commonly tampered in in-use vehicles of recent model years. It appears that disablement of oxygen sensor and removal of catalytic converters affect the emissions of THC and CO significantly. The emission of NO_x increases more due to removal of 3-way catalytic converter than because of EGR disablement. Tampered air pump system appears to affect emission of CO more than that of THC.

The emission of reactive hydrocarbons is also increased significantly by disablement of evaporative emission control system and PCV. The excess HC emission due to PCV tampering is shown in g/mi, as there should be no emission from the crankcase blowby under normal circumstances.

The impact of tampering on late model year in-use vehicles equipped with the new emission control technology has recently been investigated by EPA[85]. An earlier study[121] by EPA had shown that the THC emissions from several properly tuned, but older vehicle with high mileage, increased by

TABLE 6.9

Increase in Mean FTP Emissions Due to Tampering of Emission Control System

Emission Control System and Vehicle Type	Increase in Mean FTP Emission (%)		
	THC	CO	NO_x
Air Pump:			
Oxidation Catalyst	196	564	
3-Way Catalyst	182	791	
Catalyst Removal:			
Oxidation Catalyst	407	423	
3-Way Catalyst	467	409	304
Oxygen Sensor	445	1242	1
EGR			
Non-Catalyst			75
Oxidation Catalyst			132
3-Way Catalyst			207
Evaporative Control	128*		

* Non-methane HC

Source: 56

TABLE 6.10

Increase in Non-Exhaust Hydrocarbon Emissions Due to PCV Disablement - Light Duty Gasoline Vehicles

Vehicle Model Year	Increase in HC Emissions (g/mi)
1963-1968	3.80
1968-1970	3.74
1971-1974	3.51
1975-1977	3.44
1978-1979	3.29
1980	2.83
1981-1982	2.68
1983 and Later	2.49

Note: The primary effect of a disabled PCV system is the increase in non-exhaust HC emissions. In the absence of sufficient test data, EPA has assumed that uncontrolled crankcase emissions are proportional to the number of cylinders. Based on this assumption, it has been estimated that increases in emissions due to PCV disablement of 8-, 6-, and 4-cylinder engines would be 4.1, 3.08 and 2.05 g/mile respectively.

The average impact of PCV disablement on various model year group has been based on the estimated mix of 4-, 6- and 8-cylinder engines for each model year.

Source: 56

approximately 87% when the catalysts were removed. The emission of CO also increased significantly from the above vehicles after catalysts removal, but it was less pronounced than that occurred when certain engine parameters were maladjusted.

The extent of emission reductions associated with the repair of a single disabled component, as shown in Table 6.8, on late model vehicles has been investigated by Landman[85]. The results show that significant benefits in both THC and CO emission reductions are associated with the repair of electronic system, PCV and secondary air system, as well as with the catalyst replacement. It has been reported that amongst the various sensors the most frequent repair is needed to the oxygen sensor. By individual repair of the above components the emission reduction for THC ranged from 30% to 84% and that for CO ranged from 50% to 86%.

As shown in Table 6.8, the repair of the EGR system, which is primarily employed to control NO_x emission, is associated with an increase in THC and CO emissions by about 20% and 12% respectively. It should be noted that these figures are the averages of results from two vehicles only.

Very high levels of THC and CO are often emitted from microprocessor controlled vehicles when they are operating in a full-rich mode. This situation may result due to several reasons, including microprocessor and sensor failures, tampering and disconnection of electrical wires. During the rich mode operation of a vehicle, however, the emission of NO_x is low because of less NO_x generation by an engine under such operating conditions and the NO_x conversion efficiency of the 3-way catalyst increases under such conditions[70]. When these vehicles are repaired to reduce THC and CO emissions, the emission of NO_x tends to increase. An analysis by EPA has shown that in a "worst case" scenario only a very small, approximately 2%-2.7% increase is possible due to such repairs[112]. However, the investigation by Landman[85] has shown that there may be a NO_x penalty of as much as 26%, with corresponding reductions in THC and CO emissions of 70% and 84% respectively, after repairs of fuel-injected vehicles which had failed the Maryland I/M program. Approximately 40% of these vehicles had shown signs of either malmaintenance or tampering.

6.2.2.3 Impact of Misfueling

The effects of misfueling is somewhat difficult to ascertain since the increase in emissions occurs because of the deactivation of the catalysts as well as due to possible damage to the oxygen sensor in most late model vehicles. The extent to which a catalyst is deactivated depends on its initial conversion efficiency, besides the degree of misfueling as discussed in an earlier section. The test for the presence of lead by Plumbtesmo method may indicate that leaded fuel has been used, but it does not provide any indication of the history of such usage[107]. False negative tests may also be obtained after switching back to unleaded fuel depending on several factors as discussed below.

Several investigations[56, 122, 123] have shown that emissions of THC, CO and NO_x, depending on the type of catalytic converter used, increase steadily with misfueling. As shown in Table 6.11(a) and (b), habitual misfueling, or after 10-12 tankfulls of leaded gasoline, can cause substantial increases in emissions of all contaminants from vehicles equipped with 3-way catalytic converters. The increases in emissions of THC, CO and NO_x are 4-5 times, 2-3.5 times and 1.5-2 times respectively above the corresponding baselines. The

TABLE 6.11 (a)

Increase in Mean FTP Emissions Due to Habitual Misfueling (at least 10 tankfulls of leaded gasoline)

Vehicle Type	Increase in Mean FTP Emission (%)		
	THC	CO	NO_x
Oxidation Catalyst	329	317	
3-Way Catalyst	506	288	125
Composite of 3-Way Catalyst and 3-Way Catalyst + Oxidation Catalyst (1)	469	352	189
Composite of 3-Way Catalyst and 3-Way Catalyst + Oxidation Catalyst (2)	533	230	148

(1) 4 vehicles continuously misfueled by 10 tankfulls of leaded gasoline.

(2) 5 vehicles frequently misfueled by 12 tankfulls of leaded gasoline.

Source: 123

TABLE 6.11 (b)

Change in Conversion Efficiencies and Efficiency Losses Due to Misfueling

(Composite of 4, 3-Way Catalyst and 3-Way Catalyst + Oxidation Catalyst Vehicles)

Test	Conversion Efficiency (%)			Efficiency Loss (%)		
	THC	CO	NO_x	THC	CO	NO_x
Baseline	82	80	76	-	-	-
2 Tankfulls	54	57	74	34	29	3
4 Tankfulls	38	48	63	54	40	17
10 Tankfulls	17	31	54	79	61	29

Source: 123

emissions of THC and CO from oxidation catalyst equipped vehicles increase by about 3 times due to habitual misfueling.

It should be noted that as the tests were performed under controlled conditions on particular vehicles, the findings might not be applicable to in-use vehicles on the road in general[123]. The results, however, provide some indications on the extent of emission increases possible from misfueling. Other significant observations from these studies are summarized below.

The emission increase due to misfueling is the greatest with continuous or nearly continuous misfueling. Intermittent misfueling causes slower increases in emissions, but the emission levels may eventually increase to that of the habitually misfueled vehicles. The deactivation of the catalyst is reflected in the loss of its conversion efficiency for the specific contaminant. The catalyst conversion efficiency for all contaminants decreases with the misfueling rate, and the loss in such efficiency after 10 tankfulls of leaded gasoline has been reported to be 79%, 61% and 29% for THC, CO and NO_x respectively, as shown in Table 6.11 (b).

The catalyst seems to regain most of its conversion efficiency if the vehicles are operated on unleaded fuel after a small number of intermittent misfueling[123]. The results indicate that the most important variable affecting the emission increases is the quantity of lead consumed. While the rate of misfueling has fairly substantial impact on emission increases, vehicle mileage accumulation does not appear to have much effect.

Habitual misfueling can eventually cause a vehicle to emit THC at nearly the level of that without the catalyst, as shown in Figure 6.2. It appears that the catalysts are very sensitive to poisoning as far as the control of THC emission is concerned, in particular that of reactive hydrocarbons emissions[123]. The misfueling tests showed that in all cases the increase in the non-methane HC accounted for most of the total increase in THC emissions, and the methane fractions generally did not show any substantial increase.

It has been reported[56, 123] that misfueling affects the oxygen sensor adversely. While small amounts of misfueling may not damage the sensor badly, prolonged misfueling can affect it to cause significant impact on THC and CO emissions.

6.2.2.4 Overall Emission Reductions

Several studies[55, 100, 109, 110, 124, 125] by EPA and the state agencies in the U.S.A. have been carried out to evaluate the effectiveness of I/M programs on the fleet-wide emission reductions. Because of the variabilities involved in estimating such reductions, the findings have also been open to some criticism[55]. Despite some apparent drawbacks these investigations do provide some indications on the I/M program effectiveness.

It has been reported that since the implementation of an I/M program in 1974 in the state of New Jersey, over 17% of CO and over 12% of THC emission reductions in light duty vehicle emissions can be attributed to the I/M program[109]. As a result of the I/M program in Phoenix, Arizona since 1977, the present CO and THC emission levels there are reported to be significantly lower than before in a statistical sense[124]. The I/M program, involving only emission tests in the Seattle, Washington arera has reportedly resulted in about

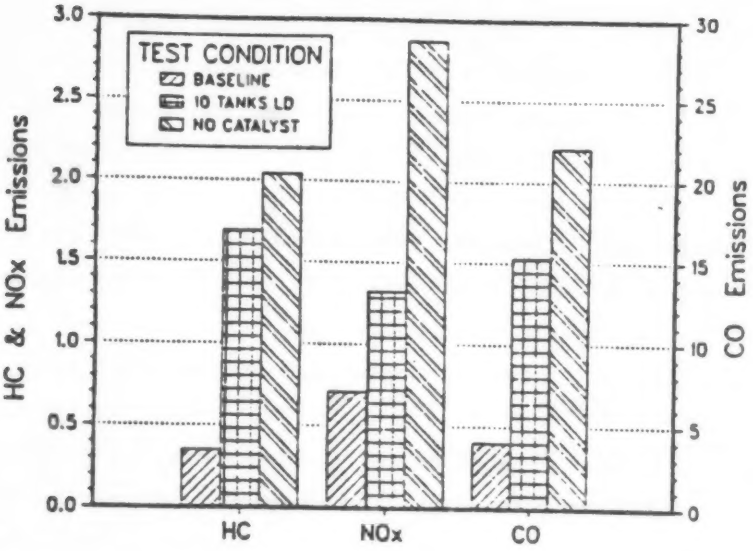


FIGURE 6.2: Effects of Habitual Misfueling and Catalyst Removal on FTP Emissions from the Continuously Misfueled Vehicles

Source: 123

28% reduction in CO emissions and 19-26% reduction in THC emissions from vehicles[125].

A comprehensive study[83] was carried out by EPA in 1976 in Portland, Oregon to evaluate the impacts of an I/M program. The results indicated that, only after one year of the I/M program, both THC and CO emission reductions immediately following maintenance were substantial. Vehicles of 1972-1974 model years which had failed the emission test showed improvements of 25% in THC and 37% in CO emissions after maintenance. The overall annual benefits from the entire fleet population of these model year vehicles were estimated to be 16% for THC and 35% for CO. The impact of the program on 1975-1977 model year vehicles was more significant. Immediately after maintenance the originally failed vehicles showed a 42% and 47% reduction fro THC and CO emissions.

The study also demonstrated the effectiveness of repairs done to the vehicles due to the I/M program. During aperiod of one year two groups of 1975-1977 model year vehicles, one from the Portland, Oregon area and another from the Eugene, Oregon area with no I/M program, were tested. The Portland vehicles had failed the initial I/M test and thus received maintenance immediately afterwards to pass, but did not undergo any further repair. The Eugene fleet, used as a control, did not receive any maintenance during the whole period. Both groups of vehicles were tested at roughly three-month intervals.

The results, as shown in Figure 6.3, indicated that the emissions from the Portland vehicles increased after the initial maintenance. Over the course of a year, the THC emission deteriorated back nearly to their original level and the emission of CO returned to approximately 60% of the original levels. The vehicles from Eugene area showed the

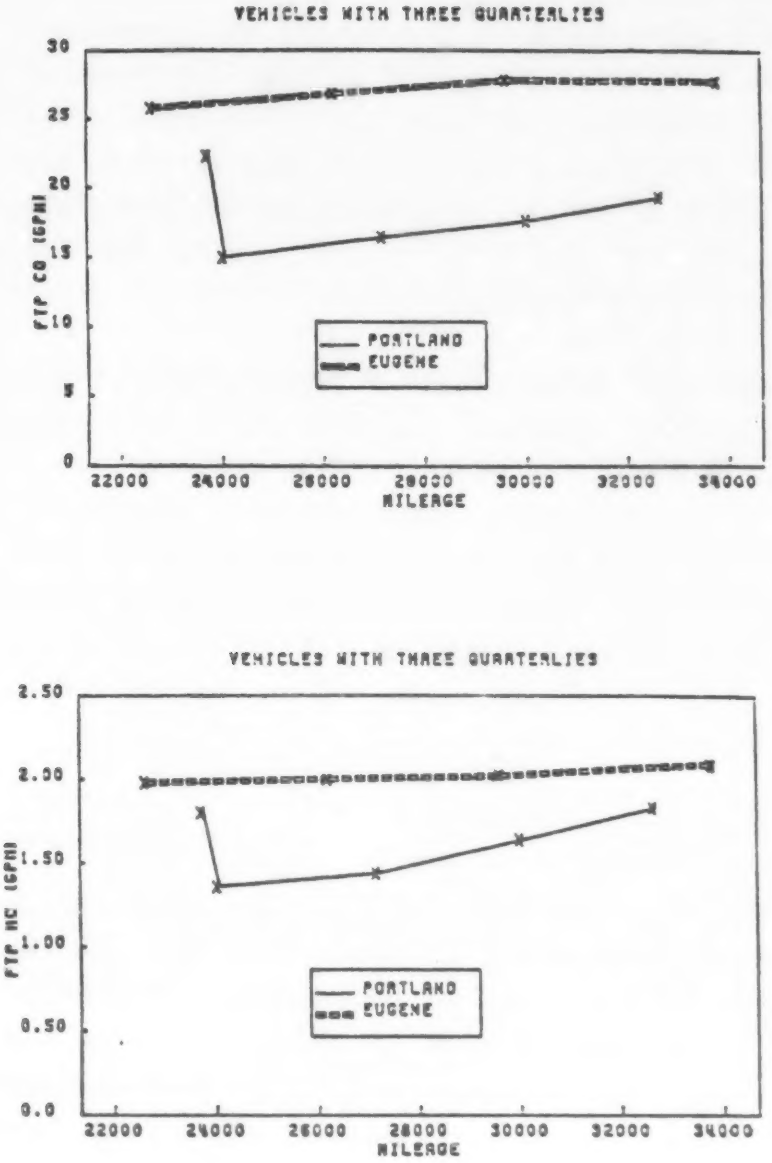


FIGURE 6.3: Comparison of Emission Deterioration Rates in I/M (Portland) and non-I/M (Eugene) Areas for the 1975 - 1977 MY Vehicles

Source: 83

typical increasing trend of emissions with age. However, the estimated benefits of the I/M program in terms of annual emission reductions from the entire fleet of these vehicles showed that Portland vehicles average 20% lower THC and 36% lower CO emissions than the Eugene vehicles. The available information indicates that total fleet emission reductions of THC and CO from propertly maintained new technolgoy vehicles as a result of I/M will likely not be as great as for maladjusted older vehicles.

With respect to deterioration, EPA's MOBILE 3 model assumes that failed and repaired vehicles in an I/M program go bad again at the same rate as those vehicles which have not failed. It has recently been reported by EPA[110] that there are some evidence that the former category vehicles fail at a higher than the average rate in the following year. Although it has not been confirmed yet, EPA suspects abnormal deterioration or repair cost waiver may be the reason for such high failure rate.

6.2.3 Fuel Economy Benefit

As carbon monoxide and hydrocarbon emissions result from inefficient combustion of the fuel in the engine, any reduction in their emissions should reflect on the fuel savings. Evaporative loss of hydrocarbons is a direct loss of the fuel. The economic benefit of fuel savings should be proportional to the emission reduction achieved by controlling evaporative emissions and by proper repair and maintenance of engine parameters which regulate combustion in the engine. Some benefit is also expected by EGR system, but other exhaust gas treatment, such as catalytic converters, does not recover any fuel value although it is the most effective device for emission control.

Although the Portland study[83] showed no fuel economy benefit from average commercial repair on pre-1981 MY vehicles, various other studies[55] showed fuel economy benefit of 3-5%. Apparently, certain repairs by untrained mechanics in Portland are now presumed to be the cause of such observations in that study. Improper retarding of the spark timing may incur a large fuel penalty of up to 20%, although such adjustments are conducive to THC emission reduction.

Any fuel economy benefits due to I/M programs involving newer technolgoy vehicles will normally be less than that from older carburetor equipped vehicles. Recent investigations[84], [85] by EPA have shown that by proper repair of failed post-1981 MY vehicles in I/M programs fuel economy benefit up to 7% can be achieved and pass the emission test applied in the programs.

7. LOWER MAINLAND VEHICLE FLEET CHARACTERISTICS

In June 1981 an inspection clinic[86] of passenger vehicles in Vancouver was set up by the Ministry of Environment and Environment Canada to gather various information on the fleet characteristics including that on exhaust emissions. The information from another recent clinic[126] in June 1986, is not available yet, as the data are still being analyzed. The relevant information from the first survey is summarized below.

A sample of 400 vehicles was surveyed which consisted of 63% North American and 37% imported from Japan and Europe. The model year of the vehicles ranged from 1982 to 1972 and older, and while 43% of the vehicles were less than 4 years old, about 22% of the fleet consisted of 10 years old and older. Both 4-cylinder and 8-cylinder vehicles represented about 39% each, and the remainder were mostly 6-cylinder vehicles. Compared to the data available from similar surveys in several other Canadian cities, the Vancouver fleet appears to consist of higher proportions of imported, older and compact vehicles. The possible reasons for these differences are the location and relatively milder climate in Vancouver.

The above survey has indicated that newer vehicles tend to be driven more than the older cars. The vehicles which were 4 years or less old and constituted about 43% of the fleet had driven nearly 50% of the total mileage driven by the whole fleet. The fleet-wide average distance travelled by a vehicle was appoximately 10,000 miles in a year. According to another survey[127] in 1980 the average number of trips made by a vehicle in the Greater Vancouver area was 3.82 per day, and the distance travelled per trip was 6.9 miles.

7.1 Tampering and Misfueling Rates

Very limited information on tampering of emission control devices in the Lower Mainland area is available. During the 1981 inspection clinic[86] 311 vehicles of model years from 1973 to 1982 were examined for EGR disablement. The general findings were that about 28% of the surveyed vehicles had EGR tampered EGR, and the tampering rate, in general, increased with the vehicle age. All the vehicles manufactured in North America, except those by General Motors, had a higher tampering rate than those imported from Europe and Japan.

A survey[128] of various muffler repair shops in 1985 has indicated that, on average, about 3% of the vehicles have their catalytic converter removed during one month period in the Lower Mainland area. The rate of such removal varied from less than 1% to as high as 20%, depending on the location of the shop.

The misfueling rate in the Lower Mainland area appears to be decreasing in the last few years. Annual surveys[88] of nozzle switching at service stations have indicated that the rate decreased from about 68% in 1983 to 7% in 1984 and about 4% in 1985. However, a more detailed survey[89] in 1985 has shown an overall misfueling rate of 13% in the area. Further breakdown of the data indicates that while about 4% of the vehicles misfueled were by nozzle switching, the majority of the vehicles (91%) were misfueled through tampered fuel inlet. Other methods, such as slow filling, funnel or adapter, were employed to misfuel the rest of the vehicles.

7.2 Estimation of Emission Factors for the Light Duty Gasoline Vehicle Fleet in the Lower Mainland Under an I/M Program

In order to assess the potential impact of an annual I/M program on emissions from automobiles it is first necessary to generate projections of emission factors for the fleet of vehicles in question. The EPA has developed a computer program that models the motor vehicle fleet in that country and calculates emission factors for various scenarios.

The current version of the Mobile Source Emission Factor Model is titled MOBILE3 and replaces MOBILE2. The Canadian version of the new MOBILE3 model, as operated by Environment Canada, is titled MOBILE3C (M3C). Only highlights and some of the qualifiers of the M3C program will be discussed here. Anyone needing a more complete description or more details of the program is referred to references 69 and 114.

7.2.1 Emission Factor Calculation Procedure

The M3C program is designed to estimate motor vehicle emission factors by vehicle type (light duty gasoline vehicles, light duty gasoline trucks, heavy duty diesel vehicles, etc.), calendar year and region (low or high altitude). It weighs emission factors (by vehicle miles travelled and vehicle population) from the past 20 model years to obtain fleet emission factors as of January 1 of the year requested by the program operator.

The emission factors are adjusted to compensate for tampering, speed, temperature, etc. and are used to calculate a composite emission factor for each vehicle type. The B.C. Ministry of Environment and Parks has decided to address only light duty gasoline vehicles (LDGV) in their proposed I/M program, therefore LDGV is the only vehicle type discussed here. In M3C a LDGV is defined as "...any gasoline fuelled automobile designed primarily for transportation of persons and having a capacity of 12 persons or fewer..."[114].

An emission factor for light duty gasoline vehicles for each model year is calculated using a generic formula, and the composite emission factor for the calendar year in question is derived by a summation over 20 model years[69].

$$\mathrm{COMEFpn} = \mathrm{SUMi}\ \{\ \mathrm{TFin} * \mathrm{SCFips} * \mathrm{BEFin}\ \} \qquad [1]$$

where: COMEFpn = The composite exhaust emission factor for pollutant p in grams/mile (g/mi) on January 1 of calendar year, n.

SUMi = The summation over 20 model years of i = n-19 to i = n, where n is the calendar year.

TFin = The fraction of the total LDGV miles driven, by model year i on January 1, of calendar year n.

SCFips = The composite speed correction factor for model year i, pollutant p and speed s.

BEFin = The basic exhaust emission factor for model year i in calendar year n.

For Total Hydrocarbons (THC) an extra factor is added to compute evaporative emissions[69].

The LDGV Basic Exhaust Emission Factors (BEFs) are based on vehicle emissions test results conducted in the U.S.A. under the standardized conditions of the FTP.

However, since in-use vehicle emissions are affected by ambient conditions and vehicle usage, which usually differ from the FTP, modifiers are applied to the zero mile emission levels (ZML) to estimate these differences.

M3C applies a variety of offsets and modifiers to estimate the BEFs used in equation [1]. They are too numerous and complex to detail in this short chapter, but a generic example is shown in equation [2].

$$BEFin = OFTAMipn + OMTCFi \; [\; ZMLip + DRip * Min \;] \qquad [2]$$

note: the Basic Emission Rate, BER = (ZML + DR * M)

where: OFTAMipn = The emission offset due to all types of tampering, corrected for temperature and operating mode, for model year i, pollutant p, in calendar year n.

OMTCFi = The composite operating mode and temperature correction factor for model year i.

ZMLip = The estimated zero mile emission rate, in g/mi, based on FTP tests, for model year i and pollutant p.

DRip = The estimated emission deterioration rate in g/mi/10000 miles, for model year i and pollutant p. The deterioration rate (based on in-use vehicle test results) adjusts the zero mile emission levels (increase) as the vehicles accumulate mileage.

Min = The model year i cumulative mileage divided by 10,000 miles, on January 1 of calendar year n.

7.2.2 Emission Factor Offsets

The offsets used in estimating BEFs according to equation [2] are briefly discussed below.

7.2.2.1 Tampering

The tampering offset allows an operator to change an emission factor to account for pollution control component tampering on vehicles in the in-use fleet. The component tampering included in M3C [and which can also be activated as part of the model's Anti-Tampering Program (ATP) provision] are: catalyst removal, air pump displacement, fuel inlet and other misfueling related tampering, EDG displacements, PCV and cannister tampering.

7.2.2.2 Temperature

While 75°F (23.9°C) is the standard temperature for the FTP, M3C allows for the input of regional or seasonal temperature values which are used in calculating temperature correction factors. These temperature correction factors alter the emission factor calculations. A summer average temperature for the Lower Mainland area is used in this exercise.

7.2.2.3 Miles Travelled

To compute the travel weighing fractions, the individual model year proportions of the total LDGV vehicle miles travelled (VMT) are required. Two of the distributions used to make these calculations are the fleet annual mileage accumulation rate distribution and the registration distribution. Examples of the two distributions, as used in MOBILE2, are shown in Tables 7.1 and 7.2.

As the Canadian data for the registration distribution and the annual mileage rate are not available, M3C still uses U.S.A. data for these two factors.

The exhaust emission rates at various mileage intervals as used in M3C are also based on the data from MOBILE 3 model.

7.2.2.4 "Canadianization"

As mentioned earlier, the model MOBILE3 has been developed by the Environmental Protection Agency in the U.S.A., and so it uses data from that country to compose the various parameters required to calculate the final emission factor estimates. However, wherever possible, attempts have been made to substitute Canadian values for the basic program matrices used in the calculations.

The only major parameter change entered into the program to date is a Canadian vehicle count to reflect the proportional difference between vehicle types in the Canadian in-use fleet.

TABLE 7.1

Estimated Mileage Accumulation Rate
(miles per vehicle)

Vehicle Age (Years)	Automobiles	Trucks			
		LDT	MDT	HDGT	HDDT
0 to 1	14400	15600	15800	21000	70400
2	13900	14000	14200	18900	66900
3	13400	12500	12600	17200	60600
4	12800	11200	11400	15500	54200
5	12300	10100	10300	14100	47900
6	11800	9400	9500	12600	43700
7	11200	8600	8700	11300	39400
8	10700	8000	8100	10300	36600
9	10200	7500	7600	9400	34500
10	9600	7000	7100	8600	33100
11	9100	6600	6600	8000	32400
12	8600	6200	6300	7300	31700
13	8000	5900	6000	6700	31000
14	7500	5500	5500	6300	29600
15	7000	5200	5200	5900	27500
16	6400	5000	5100	5500	24600
17	5900	4700	4700	5200	20400
18	5400	4400	4400	5000	17600
19	4900	4400	4400	5000	17600
20+	4300	4400	4400	5000	17600

LDT - Light Duty Truck
MDT - Medium Duty Truck
HDGT - Heavy Duty Gasoline Truck
HDDT - Heavy Duty Diesel Truck

Source: 76

TABLE 7.2

Estimated Registration Mix of the In-Use Fleet (percent of total number of vehicles)

Vehicle Age (Years)*	Automobiles	Trucks			
		LDT	MDT	HDGT	HDDT
0 to 1	2.4	3.2	8.2	0	0
2	10.1	9.4	20.7	11.4	14.2
3	9.2	8.5	15.5	8.7	8.5
4	7.1	6.1	9.7	7.3	5.9
5	9.2	9.1	5.1	8.6	9.8
6	10.3	9.9	5.6	8.8	9.3
7	8.9	7.6	3.9	7.0	7.2
8	7.1	6.0	3.0	5.3	5.2
9	6.6	4.4	2.3	4.1	4.2
10	5.9	4.8	2.0	4.4	4.2
11	4.8	4.6	1.7	4.0	3.1
12	3.5	3.3	1.1	3.1	2.4
13	3.0	3.5	1.0	3.0	2.5
14	2.3	3.3	0.8	2.6	1.9
15	1.5	2.6	0.5	2.1	1.3
16	1.0	2.1	0.6	1.8	1.0
17	0.5	1.5	0.4	1.3	0.7
18	0.3	1.1	0.3	0.9	0.4
19	0.2	1.0	0.3	0.8	0.4
20+	1.5	1.3	0.4	1.0	0.7

*January 1

LDT - Light Duty Truck
MDT - Medium Duty Truck
HDGT - Heavy Duty Gasoline Truck
HDDT - Heavy Duty Diesel Truck

Source: 76

7.2.2.5 Differences in Emission Control Technology in Canada and U.S.A.

Because of the existence of different LDGV emission standards during the period from 1981 to 1988 in the two countries, the composition of the in-use vehicle fleet in Canada is substantially different from that in the U.S.A. with respect to the proportions of various types of emission control systems fitted on these vehicles. The Canadian standards are less strict, and therefore, the penetration of 3-way catalytic converter equipped vehicles into the Canadian fleet has been much less than that in the U.S.A. In the U.S.A. the percentage of such type of vehicles in 1985 was estimated to be 39% of the fleet as shown in Table 7.3. In Canada, in the same year, the 3-way catalytic converter equipped vehicles were estimated to be 15% of the fleet.

A 3-way catalytic converter on a vehicle is significant, both from the aspect of reduced emissions because of its pollutant removal capabilities, and from the increases in emissions which can result from tampering with this system.

A first attempt to "Canadianize" the M3C internal data for pollution control technology mix by employing provincial registration data was foiled when it was found that access to the data at the technology per vehicle level was not possible. A second attempt to estimate basic emission factors using engine family sales data will not be completed in time to upgrade the Lower Mainland data.

7.2.3 Estimated Emission Factors

To run the M3C program it is necessary to input certain site-specific one-time parameters. In addition, a number of other parameters may be changed to suit the fleet undergoing

Table 7.3

British Columbia Light Duty Gasoline Vehicles - Baseline Emission Factors
(No I/M or ATP Program)

Technology U.S.A. Year	Technology B.C. Year	Total (2) Hydrocarbons	Evaporative Hydrocarbons	Carbon Monoxide	Nitrogen Oxides	Percent Oxidation Catalyst	Percent 3-Way Catalyst	Percent No Catalyst
		Light Duty Gasoline Vehicles (Passenger Automobiles) Emission Factors (in grams per mile)				Assumed Technology Penetration U.S.A.		
1975		10.49	4.39	70.14	3.88	8	0	92
76		9.61	4.07	64.95	3.70	16	0	84
77		8.88	3.80	60.58	3.53	23	0	77
78		8.22	3.51	56.93	3.34	29	0	71
79		7.48	3.09	53.92	3.19	35	0	65
1980	1980	6.85	2.72	51.05	3.06	41	1	58
81	1984	6.20	2.41	47.09	2.90	38	9	53
82	1988	5.62	2.13	43.10	2.67	35	17	48
83	89	5.10	1.90	39.44	2.47	33	24	43
84	90	4.64	1.70	36.26	2.28	30	32	38
1985	91	4.23	1.52	33.52	2.13	27	39	34
86	92	3.87	1.36	31.17	2.00	24	45	31
87	1993	3.55	1.23	29.15	1.89	22	50	28
88	94	3.28	1.12	27.46	1.80	20	55	25
89	95	3.05	1.02	26.00	1.74	18	60	22
1990	96	2.85	0.94	24.77	1.68	16	64	20
91	97	2.67	0.87	23.70	1.64	14	67	19
92	1998	2.53	0.82	22.83	1.61	13	71	16
93	99	2.41	0.78	22.09	1.58	12	74	14
94	2000	2.31	0.75	21.44	1.56	10	77	13
1995		2.23	0.73	20.98	1.55	9	79	12
96		2.17	0.71	20.65	1.54	8	81	11
97		2.13	0.69	20.37	1.54	7	83	10
98		2.09	0.68	20.14	1.54	7	84	9
99		2.06	0.67	19.86	1.54	6	86	8
2000		2.04	0.67	19.83	1.53	6	87	7

NOTES: (1) Data represents global U.S. fleet characteristics and emission control technology penetration in a British Columbia case setting, i.e. using the B.C. MOEP input data.

(2) Total hydrocarbons includes evaporative hydrocarbon emissions.

analysis; but if they are not revised the program uses its stored default values for calculating emission factors.

7.2.3.1 Input Parameters Used for the Lower Mainland

The following data, supplied by the Ministry of Environment and Parks, were used for all Lower Mainland emission factor calculations: (The numbers were brought forward to 1984 if no 1984 data were available.)

1. Vehicle population (1984) = 655,000 LDGVs

2. Total trips per day (1980) = 2.5 million
   Therefore per vehicle trips/day = 3.82*

3. Miles travelled per trip (1980) = 6.9
   Therefore miles/day/trip = 26.4*

4. Tampering rate = use default values
   M3C calculates a misfueling rate based on model year and mileage accumulation. The average default value for the fleet is approximately 13%*.

5. Light Duty Gasoline Vehicles Only = LDGV*

6. I/M Program
   Stringency Level = 30%*
   Mechanic Training = Yes*
   LDGV only = LDGV*
   Test type = Idle*
   Cutpoints = 1.5% CO*
   = 300 ppm HC*

7. Altitude = low*

8. Single average route speed = 19.7 mph*

9. Temperature - Summer = 15.5°C to 18°C
   Input the mean temperature = 62°F (16.67°C)

*Used in M3C calculations.

7.2.3.2 Assumptions Regarding Emission Control Technology Mix of the Lower Mainland Fleet

In the absence of reliable information on the composition of the Lower Mainland vehicle fleet, with respect to emission control technology, M3C still uses the program information estimated for global U.S.A. for different years. These technology mix estimates and projections, particulary that of the catalytic conversion technology, are based on the technology penetration in response to the emission standards that do, or will, apply in the U.S.A. in the year indicated. The most marked change is the introduction of 3-way catalytic converters as a result of the stricter emission standards in 1981.

The penetration of this new technology is important, as explained earlier, not only because of its effectiveness in controlling vehicle emissions, but also because of the potential overall emission reductions that could result from implementation of an I/M program in a particular area.

To estimate both baseline emission factors and the effect of an I/M program introduced in the Lower Mainland in 1988 on these emission factors, further assumptions regarding emission control technology penetration in the local vehicle fleet have also been made. As discussed in Section 7.2.2.5, it is estimated that in 1985 approximately 15% of the in-use vehicle fleet in Canada had 3-way catalytic converters. This fraction is expected to increase to about 20% by model year 1988, when the new Canadian emission standards, which are the same as that in the U.S.A. since 1981, become effective.

Therefore, in these estimations, it is assumed that the baseline U.S.A. data for 1982 was similar to the situation that would exist in the Lower Mainland in 1988. It is also assumed that the 1980 emission factors were the same in both countries, and that the year 1981 in the U.S.A. was similar to that in 1984 in Canada with respect to 3-way catalytic converter technology penetration.

7.2.3.3 Baseline Emission Factors

Using the above assumptions and the Lower Mainland input parameters listed in Section 7.2.3.1, a series of emission factors for the years 1975 to 2000 were generated and shown in Table 7.3. Emission factors were generated for THC, Evaporative Hydrocarbons (HC), CO and NO_x. It should be noted, that based on the assumptions made on control technology penetration in various years, a "B.C. Year" column was included in Table 7.3 corresponding to the U.S.A. year.

7.2.3.4 I/M Program Emission Factors

The emission factors for THC and CO under two types of I/M program, and those for NO_x under one type of I/M program, were generated for the Lower Mainland fleet for a 10-year period from 1988 to 1998. These are shown in Tables 7.4, 7.5 and 7.6, along with the corresponding baseline emission factors which represent the no I/M scenario. It should be noted that the "Year" column shown in these tables corresponds to the "B.C. Year" column displayed in Table 7.3.

The two types of I/M program for THC and CO considered are: (1) the conventional I/M program involving emission testing as designated by I/M only, and (2) a combined program of I/M only and an anti-tampering program (ATP) as designated by I/M and ATP. An ATP involves a visual inspection of certain emission control systems and a Plumbtesmo test for lead in the vehicle tailpipe.

Table 7.4

British Columbia Light Duty Gasoline Vehicles
Impact Of I/M and Both I/M & ATP On Total Hydrocarbon (THC) Emission Factors

	Baseline - No I/M		I/M Only (1)			I/M and ATP (1,2)		
	THC		THC	Decr. from Baseline		THC	Decr. from Baseline	
	"A"	% decrease	"B"	"A-B"	as % of A	"C"	"A-C"	as % of A
Year	g/mi	per year	g/mi	g/mi	per year	g/mi	g/mi	per year
1984	6.20	---						
85	6.06	2.3						
86	5.91	2.5						
87	5.77	2.5						
1988	5.62	2.6	5.62	0.00	0.0	5.62	0.00	0.0
89	5.10	9.3	4.71	0.39	7.7	4.47	0.63	12.4
90	4.64	9.0	4.16	0.48	10.3	3.91	0.73	15.7
91	4.23	8.8	3.71	0.52	12.3	3.47	0.76	18.0
92	3.87	8.5	3.32	0.55	14.2	3.08	0.79	20.4
1993	3.55	8.3	2.99	0.56	15.8	2.75	0.80	22.5
94	3.28	7.6	2.71	0.57	17.4	2.48	0.80	24.4
95	3.05	7.0	2.48	0.57	18.7	2.26	0.79	25.9
96	2.85	6.6	2.29	0.56	19.7	2.07	0.78	27.4
97	2.67	6.3	2.12	0.55	20.6	1.91	0.76	28.5
1998	2.53	5.2	2.00	0.53	21.0	1.80	0.73	28.9
99	2.41	4.7						
2000	2.31	4.1						

Decrease From 1988 Baseline

	Baseline - No I/M		I/M Only (1)		I/M & ATP (1,2)	
	g/mi	%	g/mi	%	g/mi	%
After 5 years (1993-88)						
	2.07	36.8	2.63	46.8	2.87	51.1
After 10 years (1998-88)						
	3.09	55.0	3.62	64.4	3.82	68.0

NOTES:

1) Inspection and Maintenance (I/M) Program Criteria:
1.5% Idle CO, 300 ppm Idle HC, 30% OxCat Failure Rate.

2) Anti-Tampering Program (ATP) Criteria:
Annual Inspection of all LDGVs up to ten years old for Catalyst Removal, Air Pump Disablement, Fuel Inlet and Other Misfueling (Plumbtesmo), EGR Disablements, PCV and Canister Tampering.

3) THC or Total Hydrocarbons includes evaporative emissions.

4) Calculations are post-ATP subroutine corrections to M3C.

Table 7.5

British Columbia Light Duty Gasoline Vehicles
Impact Of I/M And Both I/M & ATP On Carbon Monoxide (CO) Emission Factors

	Baseline - No I/M		I/M Only (1)			I/M and ATP (1,2)		
				Decr. from Baseline			Decr. from Baseline	
Year	CO "A" g/mi	% decrease per year	C) "B" g/mi	"A-B" g/mi	as % of A per year	CO "C" g/mi	"A-C" g/mi	as % of A per year
1984	47.09	---						
85	46.09	2.1						
86	45.10	2.2						
87	44.10	2.2						
1988	43.10	2.3	43.10	0.00	0.0	43.10	0.00	0.0
89	39.44	8.5	31.20	8.24	20.9	29.11	10.33	26.2
90	36.26	8.1	25.24	11.02	30.4	23.13	13.10	36.2
91	33.52	7.6	21.90	11.62	34.7	19.81	13.71	40.9
92	31.17	7.0	19.64	11.53	37.0	17.56	13.61	43.7
1993	29.15	6.5	17.90	11.25	38.6	15.86	13.29	45.6
94	27.46	5.8	16.64	10.82	39.4	14.65	12.81	46.7
95	26.00	5.3	15.64	10.36	39.9	13.71	12.29	47.3
96	24.77	4.7	14.86	9.91	40.0	13.00	11.77	47.5
97	23.70	4.3	14.12	9.58	40.4	12.34	11.36	47.9
1998	22.83	3.7	13.78	9.05	39.6	12.07	10.76	47.1
99	22.09	3.2						
2000	21.44	2.9						

Decrease From 1988 Baseline

	Baseline - No I/M		I/M Only (1)		I/M & ATP (1,2)	
	g/mi	%	g/mi	%	g/mi	%
After 5 years (1993-88)						
	13.95	32.4	25.20	58.5	27.24	63.2
After 10 years (1998-88)						
	20.27	47.0	29.32	68.0	31.03	72.0

NOTES:

1) Inspection and Maintenance (I/M) Program Criteria:
1.5% Idle CO, 300 ppm Idle HC, 30% OxCat Failure Rate.

2) Anti-Tampering Program (ATP) Criteria:
Annual Inspection of all LDGVs up to ten years old for Catalyst Removal, Air Pump Disablement, Fuel Inlet and Other Misfueling (Plumbtesmo), EGR Disablements, PCV and Canister Tampering.

3) Calculations are post-ATP subroutine corrections to M3C.

TABLE 7.6

British Columbia Light Duty Gasoline Vehicles Impact of I/M & ATP on Oxides of Nitrogen (NO_x) Emission Factors

	Baseline - No I/M		I/M and ATP (1,2)		
			NOx	Decr. from Baseline	
Year	NOx "A" g/mi	% decrease per year	"C" g/mi	"A-C" g/mi	as % of A per year
1984	2.90	--			
85	2.84	2.1			
86	2.79	1.8			
87	2.73	2.2			
1988	2.67	2.2	2.67	0.00	0.0
89	2.47	7.5	2.47	0.00	0.0
90	2.28	7.7	2.28	0.00	0.0
91	2.13	6.6	2.11	0.02	0.9
92	2.00	6.1	1.97	0.03	1.5
1993	1.89	5.5	1.86	0.03	1.6
94	1.80	4.8	1.76	0.04	2.2
95	1.74	3.3	1.68	0.06	3.4
96	1.68	3.4	1.61	0.07	4.2
97	1.64	2.4	1.56	0.08	4.9
1998	1.61	1.8	1.51	0.10	6.2
99	1.58	1.9			
2000	1.56	1.3			

Decrease from 1988 Baseline

	Baseline - No I/M		I/M & ATP (1,2)	
	g/mi	%	g/mi	%
After 5 years (1993-88)	0.78	29.2	0.81	30.3
After 10 years (1998-88)	1.06	39.7	1.16	43.4

Notes:

1) Inspection and Maintenance (I/M) Program Criteria:
   1.5% Idle CO, 300 ppm Idle HC, 30% OxCat Failure Rate.

2) Anti-Tampering Program (ATP) Criteria:
   Annual Inspection of all LDGVs up to ten years old for Catalyst Removal, Air Pump Disablement, Fuel Inlet and Other Misfuelling (Plumbtesmo), EGR Disablements, PCV and Cannister Tampering.

3) Calculations are post-ATP subroutine corrections to M3C.

As the oxides of nitrogen are not generated in any significant quantity during the idle test of a vehicle, and therefore are not measured in the exhaust emissions, a conventional I/M program is ineffective in controlling NO_x emissions. Hence, the emission factors generated for this contaminant by MOBILE3C under the I/M and ATP program, in fact, represents the impact of ATP only.

It should be noted that the per year emission factor decreases shown in Tables 7.4 to 7.6 are not cumulative, but they only represent an additional estimated decrease over the corresponding baseline emission factor in the given year studied.

7.2.4 Impacts of I/M Programs on Total Hydrocarbons Emission Factor

An examination of the baseline emission factors for THC, Table 7.4, reveals that as a result of a greater number of vehicles equipped with better emission control technology entering the in-use fleet each year, the composite fleet emission factor for THC decreases each year from 1984 to 2000. For a 5 year period, 1988 to 1993, the estimated decrease in the combined exhaust and evaporative emission factor is 2.07 g/mi which is 36.8% of the 1988 emission factor of 5.62 g/mi. Similarly, for a 10 year period, 1988 to 1998, the estimated emission factor decrease is 3.09 g/mi or 55% of the 1988 value.

From Table 7.4 it appears that the estimated emission factor for THC may be reduced by additional amounts after implementation of an I/M and I/M and ATP. For example, it is expected that in 1989 the THC emission factor would decrease an additional 7.7% and 12.4% of the corresponding baseline emission factor as a result of an I/M and I/M and ATP respectively.

As shown in Table 7.4 the impacts of an I/M only and I/M and ATP program after 5 years, and 10 years on the THC emission factor are expected to be significant in comparison to the corresponding baseline emission factor. The estimates show that by implementing an I/M only program in 1988 the THC emission factor in 1993 is expected to be decreased by 46.8%, as compared to the 36.8% reduction in the baseline emission factor in 1993. The corresponding decrease in emission factor with an I/M and ATP is estimated to be 51.1%, indicating the additional benefit of adding an ATP to an I/M program.

7.2.5 Impacts of I/M Programs on Carbon Monoxide Emission Factor

The baseline emission factors for CO, as shown in Table 7.5, also reveal a per year decrease from 1984 to 2000 as a result of newer pollution control technology vehicles replacing older models. The emission factor decrease from 1988 to 1993 is estimated at 13.95 g/mi or 32.4% and the decease from 1988 to 1998 at 20.27 g/mi or 47.0%.

The projected decrease in the composite emission factor from an I/M plus ATP program for a five year period from 1988 to 1993 is 27.24 g/mi or an additional 30.8% decrease over the No-I/M case, for a total composite emission factor that is 63.2% lower than the 1988 baseline. The decrease for the 10 year period, 1988 to 1998, is 31.03 g/mi or 25% lower than the No I/M case. The total for the period is 72% lower than the 1988 baseline estimate.

7.2.6 Impact of an ATP Program on Nitrogen Oxides Emission Factor

The estimated data presented in Table 7.6 indicate that as the new control technology, principally the 3-way catalytic converter, penetrates into the Lower Mainland fleet, the composite emission factor for NO_x decreases every year after 1984. The impact of the new emission standards for 1988+ MY vehicles on the NO_x emission factor is also reflected in the percentage decrease per year from 1989 onwards. The NO_x emission factor is estimated to decrease 29.2% between 1988 and 1993 and 39.7% between 1988 and 1998.

As explained in Section 7.2.3.4, the emission factors shown under I/M and ATP column in Table 7.6 are the impacts of an ATP program only. The effect of such a program after 5 years is estimated to be an additional decrease of 1.1% in the emission factor over the baseline estimate. After ten years of a similar program, such additional benefit is expected to be 3.7% only.

7.2.7 Emission Factors for THC and HC Fractions

Because of the significance of hydrocarbon emissions, particularly that of HC emissions through the vehicle exhaust as well as evaporative sources, MOBILE3C has also been used to estimate emission factors for HC emissions separately from these sources. In addition, emission factors have been estimated for hydrocarbons under an ATP program only as shown in Table 7.7. The emission factors in this table are presented as fractions of the 1988 baseline emission factor for THC under each I/M program scenario. The data given in the above table have been used with those shown in Table 7.4 to estimate the emission reductions in the following sections.

7.3 Estimated Impact of an I/M Program on Emission Reductions

The emission factors generated by the computer program M3C for different scenarios with respect to an I/M program for

TABLE 7.7

Estimated Emission Factors for THC, HC and Evaporative HC Under Different I/M Scenarios in the Lower Mainland

(Emission Factors as Fractions of 1988 Baseline THC Emission Factor shown in Table 7.4)

Year	Baseline			I/M			ATP			I/M + ATP		
	THC	HC	Evap. HC	THC	HC	Evap. HC	THC	HC	Evap. HC	THC	HC	Evap. HC
1988	1.00	0.96	0.38	1.00	0.96	0.38	1.00	0.96	0.38	1.00	0.98	0.38
1989	0.91	0.87	0.34	0.84	0.81	0.34	0.86	0.83	0.33	0.80	0.77	0.33
1990	0.83	0.79	0.30	0.74	0.71	0.30	0.77	0.74	0.29	0.70	0.67	0.29
1991	0.75	0.72	0.27	0.66	0.64	0.27	0.70	0.66	0.26	0.62	0.59	0.26
1992	0.69	0.66	0.24	0.59	0.57	0.24	0.63	0.60	0.23	0.55	0.52	0.23
1993	0.63	0.60	0.22	0.53	0.51	0.22	0.57	0.54	0.21	0.49	0.47	0.21
1994	0.58	0.56	0.20	0.48	0.46	0.20	0.52	0.49	0.19	0.44	0.42	0.19
1995	0.54	0.52	0.18	0.44	0.42	0.18	0.48	0.45	0.17	0.40	0.38	0.17
1996	0.51	0.49	0.17	0.41	0.39	0.17	0.44	0.42	0.16	0.37	0.35	0.16
1997	0.48	0.45	0.15	0.38	0.36	0.15	0.41	0.39	0.15	0.34	0.32	0.15
1998	0.45	0.43	0.15	0.36	0.34	0.15	0.39	0.36	0.14	0.32	0.30	0.14

THC - Total hydrocarbon emission includes exhaust and evaporative emissions.

HC - Non-methane hydrocarbons.

Evap. HC - Evaporative hydrocarbon emissions.

Baseline - Impact on emission factors due to introduction of new emission standards for 1988 + MY vehicles.

LDGVs in the Lower Mainland are used to estimate the emissions of THC, HC, CO and NO_x from this particular source. To project these emissions into the year 2000 and to estimate their contributions to the total emissions in the area, the following assumptions have been made.

The vehicle population in the area will grow at a compounded annual rate of 2% each year. The total miles travelled annually by each vehicle will remain the same. There will be no further changes in the emission standards or any penetration of superior emission control technology in the vehicle fleet during the period 1988-1998.

As the MOBILE3C program has been run to estimate the emission factors for the contaminants until 1998 for scenarios with I/M and I/M + ATP, extrapolated values for the years 1999 and 2000 have been used in these estimations. Similar extrapolation method has been employed to estimate the technology mix of the Lower Mainland fleet from Table 7.3 for the years 1986 and 1987, and the information is used in estimating the impacts on emission due to misfueling.

In the absence of any emission inventory data for any year later than 1980, it has been assumed that the emissions of THC, CO and NO_x from all sources, other than automobiles, will remain constant at 1980 levels in the area through to the year 2000. This assumption is based on the trends in the emissions of these contaminants from all sources in the whole province during the period from 1970 to 1980[129]. This trend analysis, based on biennial inventories, does not indicate any clear trend of either increase or decrease in total emissions of these contaminants.

As noted in an earlier section and Table 2.1, the estimated THC emission from solid waste landfills in 1980 was 98,647 tonnes. However, the hydrocarbons emitted from landfills reportedly consist of approximately 99.7% methane and ethane which do not contribute towards the oxidants formation[7]. Hence, the THC contribution from this source has been excluded from the total emission, and is unlikely to affect the present analysis in any significant manner.

7.3.1 Emission Reductions: 1986-2000

Based on the above assumptions and the composite emission factors developed by MOBILE3C, the emissions of THC, CO and NO_x from the automobiles in the Lower Mainland area have been estimated for each year from 1986 to 2000 under different scenarios with respect to an I/M program. The estimated emission reductions during the above period are summarized in Table 7.8, and shown in Figures 7.1 to 7.3. It appears that with the introduction of new emission standards for 1988 + MY vehicles, the emissions of THC, CO and NO_x from automobiles would decline by 19,700, 115,800 and 5,000 tonnes respectively by the year 2000. These reductions represent approximately 48%, 37% and 26% of THC, CO and NO_x respectively. In terms of emission inventory for the area, these vehicular emission improvements would mean area-wide reductions of THC by 20%, CO by 19% and NO_x by 6%.

In the event of implementation of a conventional I/M program involving exhaust emission testing in 1988 for the light duty gasoline vehicles in the area, the projected THC emission in the year 2000 shows an additional reduction of approximately 12% in vehicular emissions. The estimated additional benefit in terms of area-wide reduction in total THC emissions from all sources would be about 5%.

Instead of a conventional I/M, if an ATP program is implemented in 1988, the estimated THC emission from automobiles in the year 2000 would be approximately 8% less than that would be without any program. This would result in

TABLE 7.8

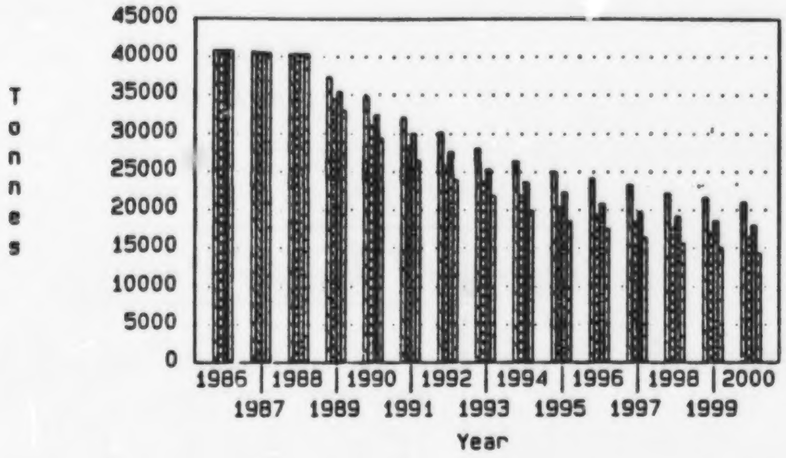
Estimated Reductions in Emissions Under Different I/M Scenarios in the Lower Mainland for the Period 1986-2000

Scenario	Light Duty Gasoline Vehicles Emissions						Reduction in Total Emissions from All Sources		
	Emission Reduction								
	x10^3 tonnes			%			%		
	THC	CO	NOx	THC	CO	NOx	THC	CO	NOx
NO I/M Program (New Emission Standard)	19.7	115.8	5.0	48.4	37.3	26.2	20.0	18.6	5.6
I/M Program	24.4	191.4	-	59.8	61.6	-	24.7	30.8	-
ATP Program	22.8	-	6.1	56.0	-	31.9	23.2	-	6.8
I/M + ATP Program	26.4	205.8	*	64.9	66.2	*	26.9	33.1	*

* Similar reduction as with ATP Program is expected.

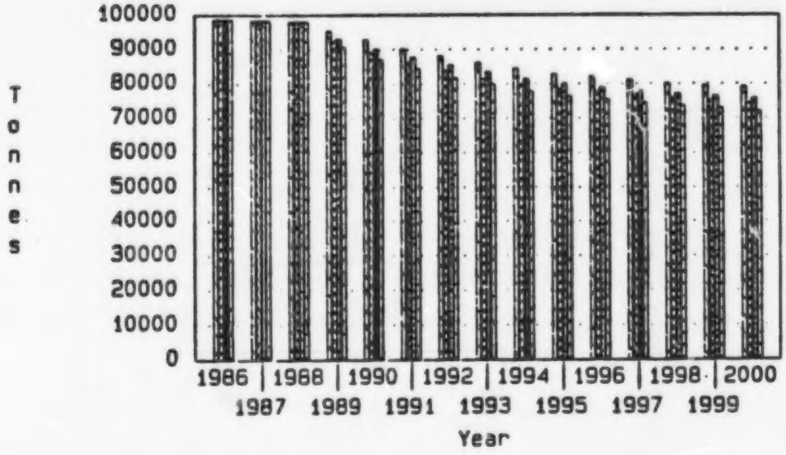
Notes:
1. Estimates are based on 1986 baseline data as explained in the text.
2. New emission standards will be effective with 1988 MY vehicles.
3. I/M, ATP or I/M + ATP program starts on January 1, 1988.

THC (Light Duty Gasoline Vehicles)



(Emissions)

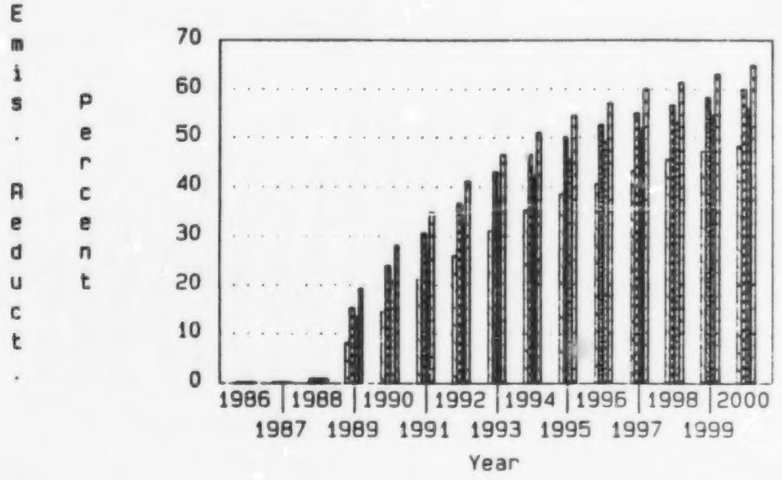
THC (Total)



(Emissions)

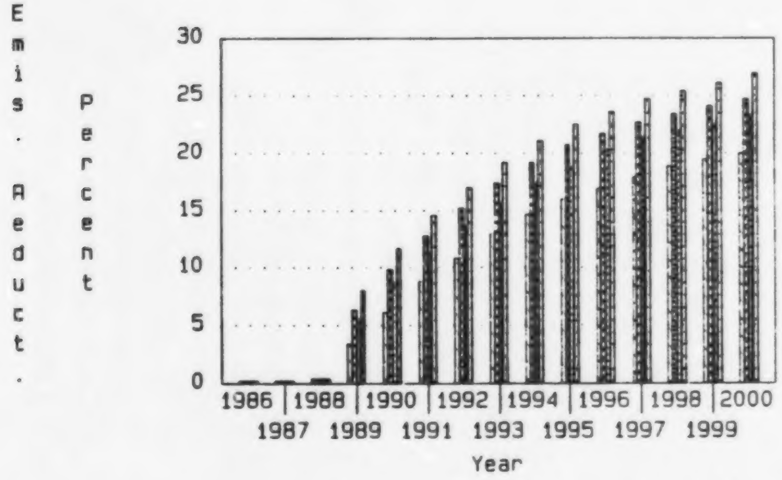
▧ NES - New Emission Standards
▩ I/M - Inspection/Maintenance
▦ ATP - Anti-Tampering and Misfueling
▤ I/M+ATP - Inspection/Maintenance and Anti-Tampering and Misfueling

FIGURE 7.1(a): Estimated Emissions and Emission Reductions of THC from Light Duty Gasoline Vehicles Under Different I/M Program Scenarios - 1986-2000



THC (Light Duty Gasoline Vehicles)

(Emission Reduction based on 1986 Baseline)



THC (Total)

(Emission Reduction based on 1986 Baseline)

▧ NES - New Emissions Standards
▩ I/M - Inspection/Maintenance
▥ ATP - Anti-Tampering and Misfueling
▤ I/M+ATP - Inspection/Maintenance and Anti-Tampering and Misfueling

FIGURE 7.1(b): Estimated Emissions and Emission Reductions of THC from All Sources Under Different I/M Program Scenarios - 1986-2000

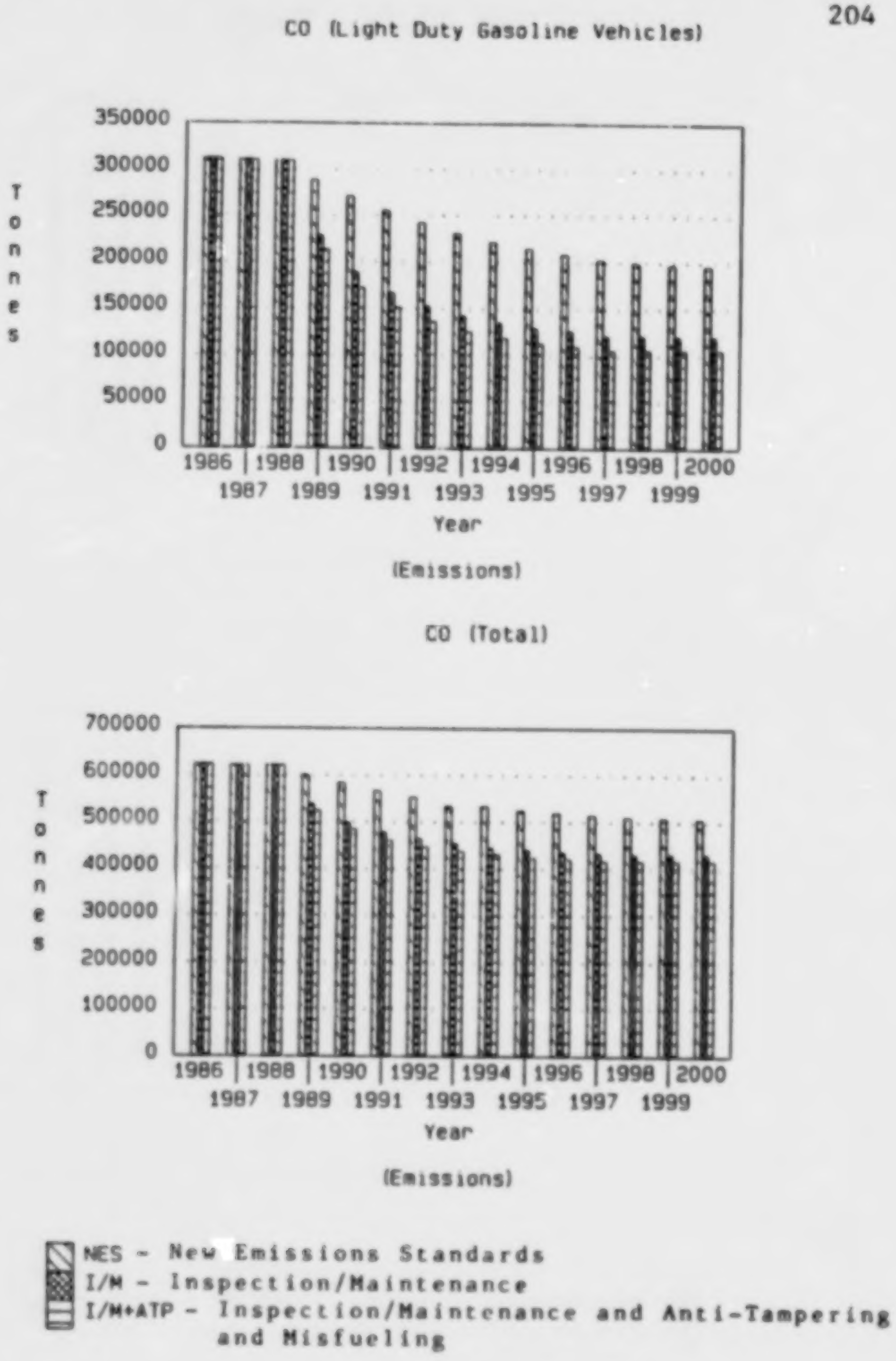


FIGURE 7.2(a): Estimated Emissions and Emission Reductions of CO from Light Duty Gasoline Vehicles Under Different I/M Program Scenarios - 1986-2000

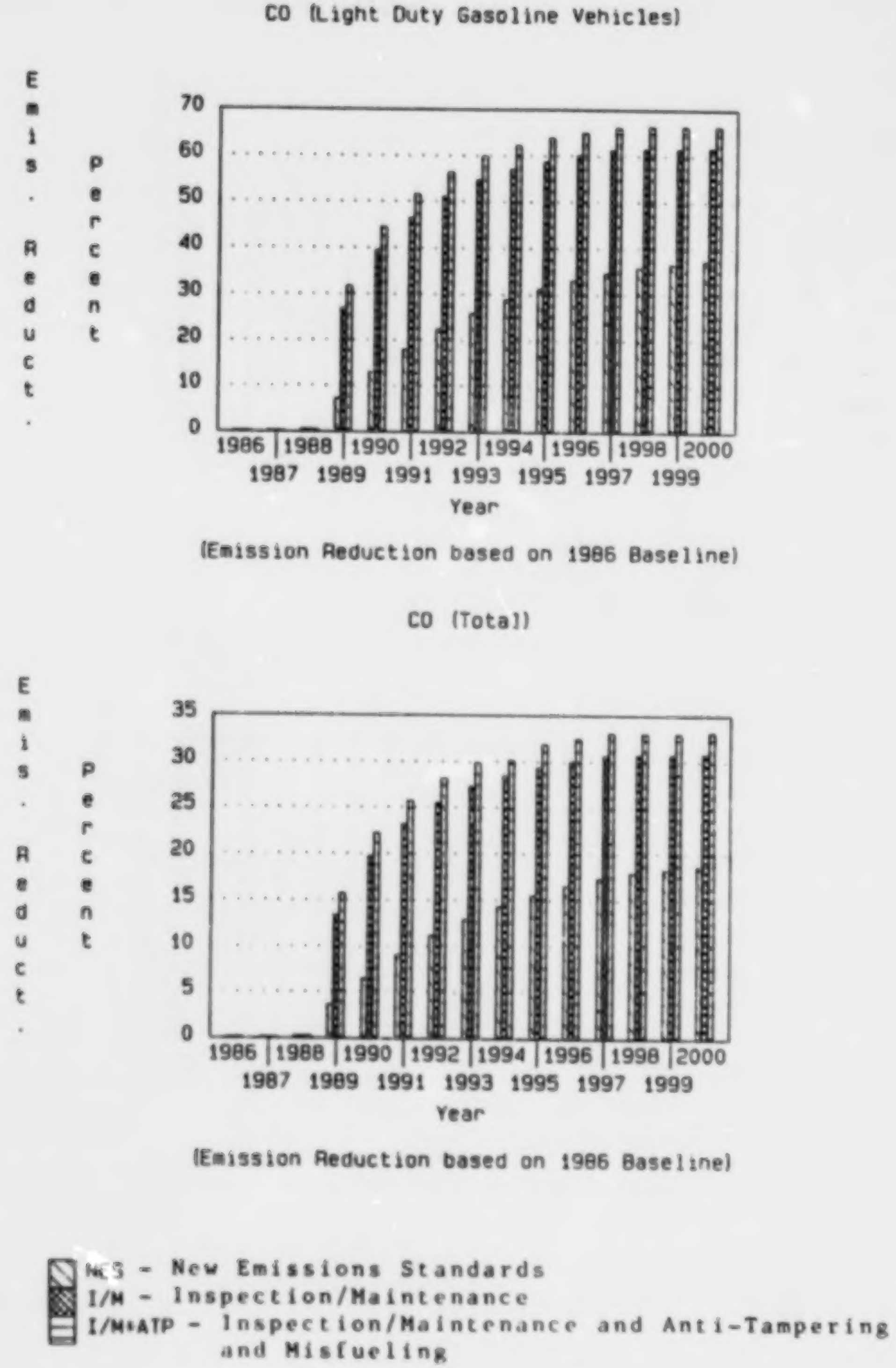


FIGURE 7.2(b): Estimated Emissions and Emission Reductions of CO from All Sources Under Different I/M Program Scenarios - 1986-2000

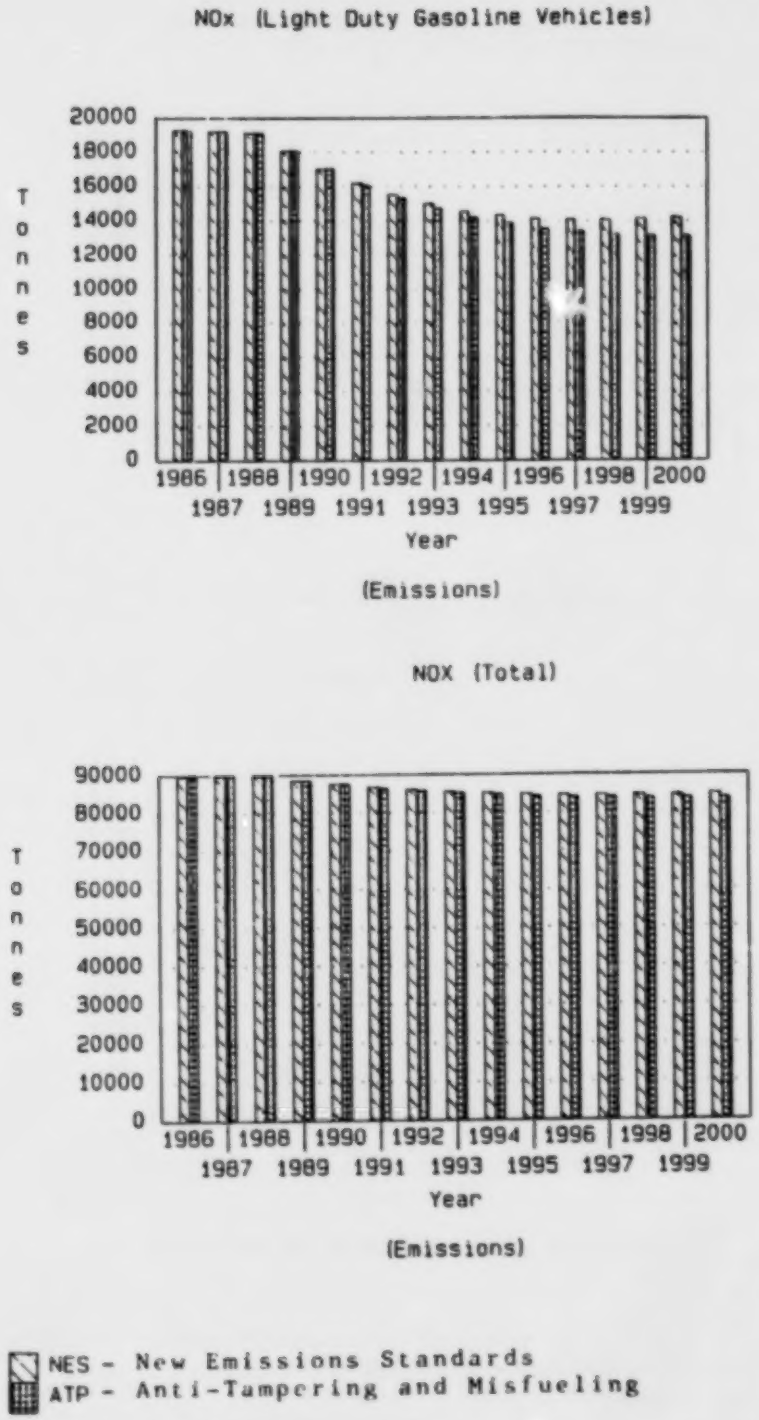
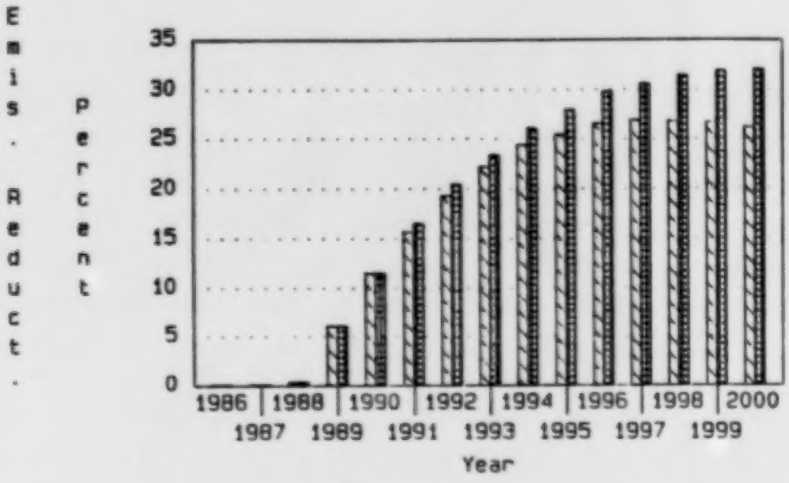


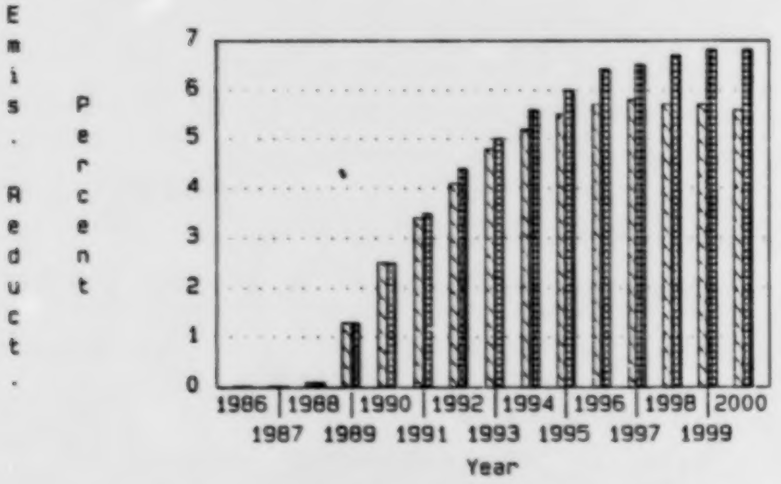
FIGURE 7.3(a): Estimated Emissions and Emission Reductions of NO_x from Light Duty Gasoline Vehicles Under Different I/M Program Scenarios - 1986-2000

NOx (Light Duty Gasoline Vehicles)



(Emission Reduction based on 1986 Baseline)

NOx (Total)



(Emission Reduction based on 1986 Baseline)

▨ NES - New Emissions Standards
▦ ATP - Anti-Tampering and Misfueling

FIGURE 7.3(b): Estimated Emissions and Emission Reductions of NO_x from All Sources Under Different I/M Program Scenarios - 1986-2000 about 3% reduction in THC emissions from all sources in the area during the same time period. It is apparent that the maximum benefit could be achieved by implementing a comprehensive program of an I/M and an ATP in 1988. By the year 2000 such a program would result in about 17% more reduction in vehicular THC emission than that could be achieved by new emission standards. Such reductions in automobile emissions would correspond to an overall decrease of an additional 7% in THC emission from all sources in the area during the above period.

The impact of an I/M program on CO emission from automobiles would be an additional 25% reduction by the year 2000, and a concomitant reduction of approximately 12% of the total CO emission from all sources in the area during the same period. Further benefit from reduction in CO emission could result if an I/M, program is combined with an ATP program. The impact of a combined program has been estimated to be an incremental benefit of about 4% reduction in automobile CO emission and approximately 2% reduction in the total CO emission for the area by the year 2000. No estimates of CO emission has been done under an anti-tampering and misfueling program scenario only.

A conventional I/M program would not result in any significant reduction in NO_x emissions because of the program features described earlier. An ATP program, however, could result in about 6% and 1% reduction in NO_x emissions from automobiles and all sources in the area respectively, over and above the corresponding reductions estimated to occur by the year 2000 as a result of the new emission standards.

7.3.2 Emission Reductions: 1988-1993 and 1988-1998

In order to assess the impacts of the scenarios, similar to those considered in the previous section, on the emission reductions during a short term (5-year) and a long term (10-year) period, further estimates of emissions have been carried out. The estimated reductions in emissions of THC, CO and NO_x after the above periods are summarized in Table 7.9, and illustrated in Figures 7.4 to 7.6.

As the relative impacts of an I/M, an ATP, and an I/M + ATP with respect to that of the new vehicle emission standards are similar to those estimated for the period 1986-2000, and the data, presented in Table 7.8 and Figures 7.1 to 7.3, are self-explanatory, no additional comments are considered necessary. One important observation that could be made is that the major benefits in emission reductions for all contaminants are achieved after the first 5-year period. In comparison to these initial reductions in emissions, the incremental benefits accrued after a 10-year period appear to be rather small for all contaminants.

7.3.3 Reductions in Emissions of Hydrocarbons

Because of the role of the reactive hydrocarbons in the photochemical oxidants formation, estimates of reductions in the HC fraction of the THC emissions have also been made for various scenarios and summarized in Table 7.10 and Figure 7.7. As no information on the HC emission inventory from different sources in the area is available, the above estimates are restricted to emissions from the light duty gasoline vehicles only.

It should be noted that the THC emission values consist of both non-methane reactive hydrocarbons (HC) and other non-reactive hydrocarbons, and the HC fraction also represents any reactive hydrocarbons estimated to have emitted from the evaporative sources in a vehicle. As

TABLE 7.9

Estimated Reductions in Emissions Under Different I/M Scenarios in the Lower Mainland for the Period 1988-1993 and 1988-1998

(Reductions are relative to 1988 emissions)

Period	Scenario	Light Duty Gasoline Vehicles Emissions						Reduction in Total Emissions from All Sources		
		Emission Reduction								
		x10^3 tonnes			%			%		
		THC	CO	NOx	THC	CO	NOx	THC	CO	NOx
1988 - 1993	No I/M Program (New Emission Standard)	12.3	78.2	4.2	30.5	25.3	21.8	12.5	12.6	4.7
	I/M Program	16.7	167.3	-	41.5	54.1	-	17.0	27.0	-
	ATP Program	15.0	-	4.4	37.1	-	23.1	15.3	-	4.9
	I/M + ATP Program	18.5	183.4	*	46.0	59.4	*	18.9	29.6	*
1988 - 1998	No I/M Program (New Emission Standard)	18.2	109.4	5.1	45.1	35.4	26.5	18.5	17.6	5.7
	I/M Program	22.6	188.5	-	56.2	61.0	-	23.0	30.4	-
	ATP Program	21.1	-	5.9	52.5	-	31.1	21.6	-	6.6
	I/M + ATP Program	24.6	203.5	*	61.0	65.9	*	25.0	32.8	*

* Similar reduction as with ATP Program is expected.

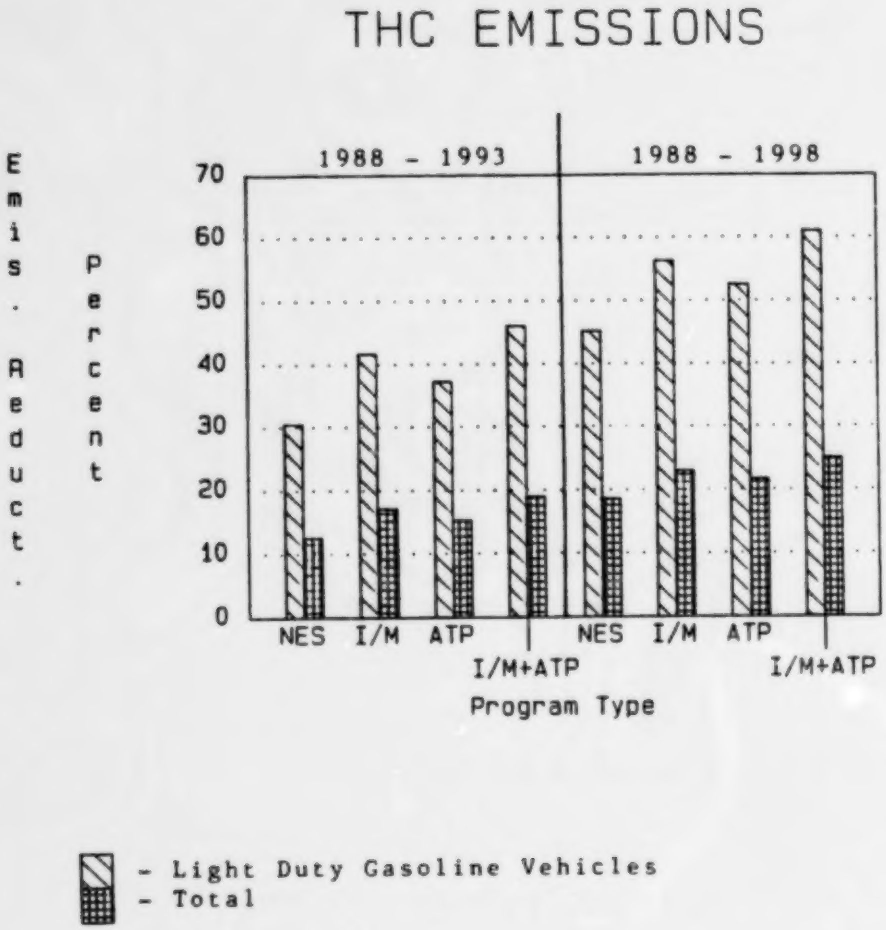


FIGURE 7.4: Percentage Reduction in THC Emissions Under Different I/M Program Scenarios After 5 and 10 Years (From 1988 Baseline Emissions)

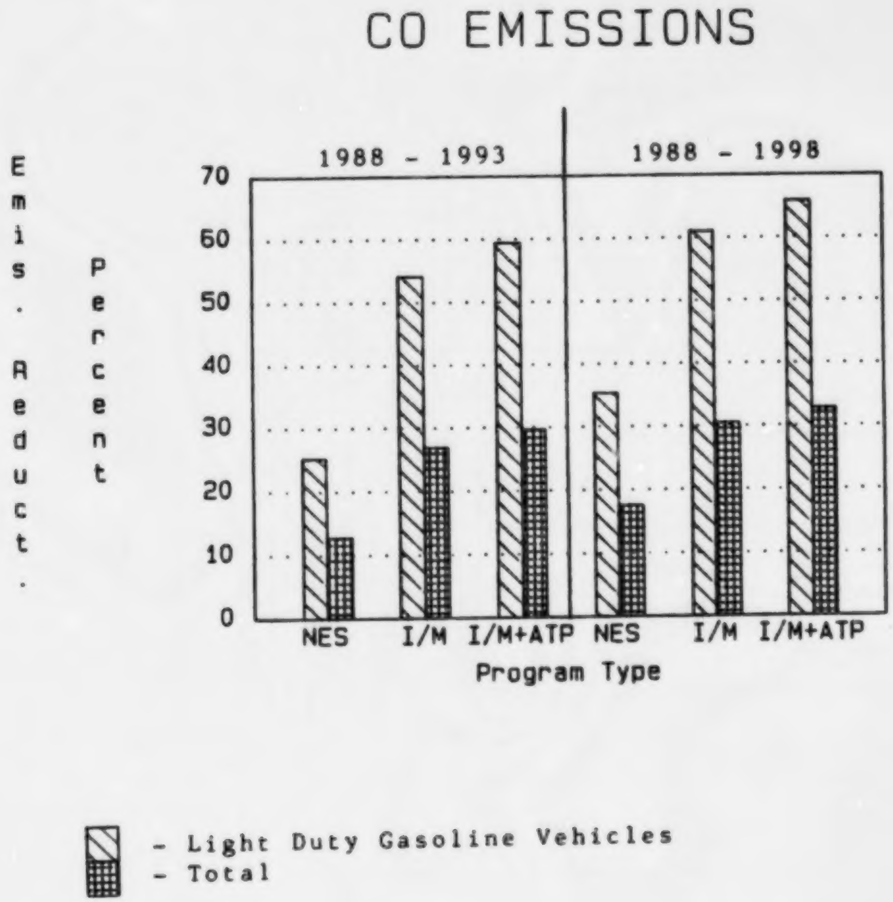


FIGURE 7.5: Percentage Reduction in CO Emissions Under Different I/M Program Scenarios After 5 and 10 Years (From 1988 Baseline Emissions)

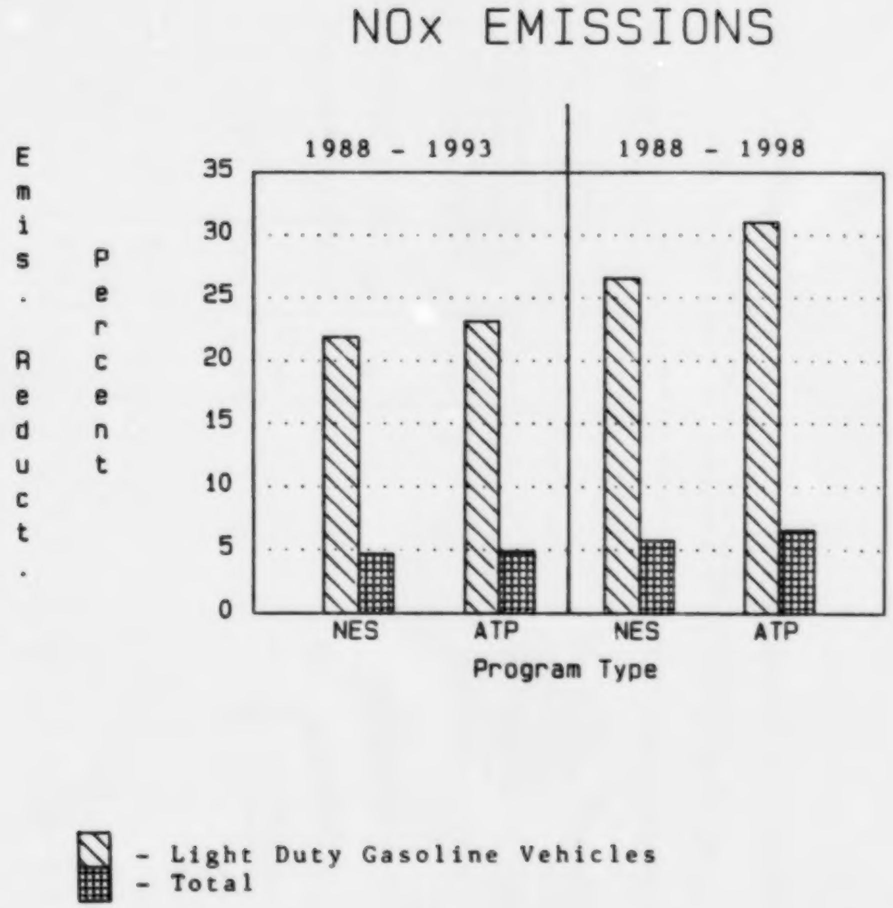


FIGURE 7.6: Percentage Reduction in NO_x Emissions Under Different I/M Program Scenarios After 5 and 10 Years (From 1988 Baseline Emissions)

TABLE 7.10

Estimated Reductions in Emissions Under Different I/M Scenarios in the Lower Mainland for the Period 1988-1993 and 1988-1998

(Reductions are relative to 1988 emissions)

Period	Scenario	Light Duty Gasoline Vehicles Emissions					
		x10^3 tonnes			%		
		THC	HC	Evaporative HC	THC	HC	Evaporative HC
1988 - 1993	No I/M Program (New Emission Standard)	12.3	12.0	5.5	30.5	31.1	36.2
	I/M Program	16.7	16.0	-	41.5	41.3	-
	ATP Program	15.0	14.7	5.9	37.1	38.0	38.8
	I/M + ATP Program	18.5	17.8	-	46.0	46.0	-
1988 - 1998	No I/M Program (New Emission Standard)	18.2	17.6	8.1	45.1	45.4	53.1
	I/M Program	22.6	22.0	-	56.2	56.9	-
	ATP Program	21.1	21.0	8.4	52.5	54.4	54.8
	I/M + ATP Program	24.6	23.9	-	61.0	61.8	-

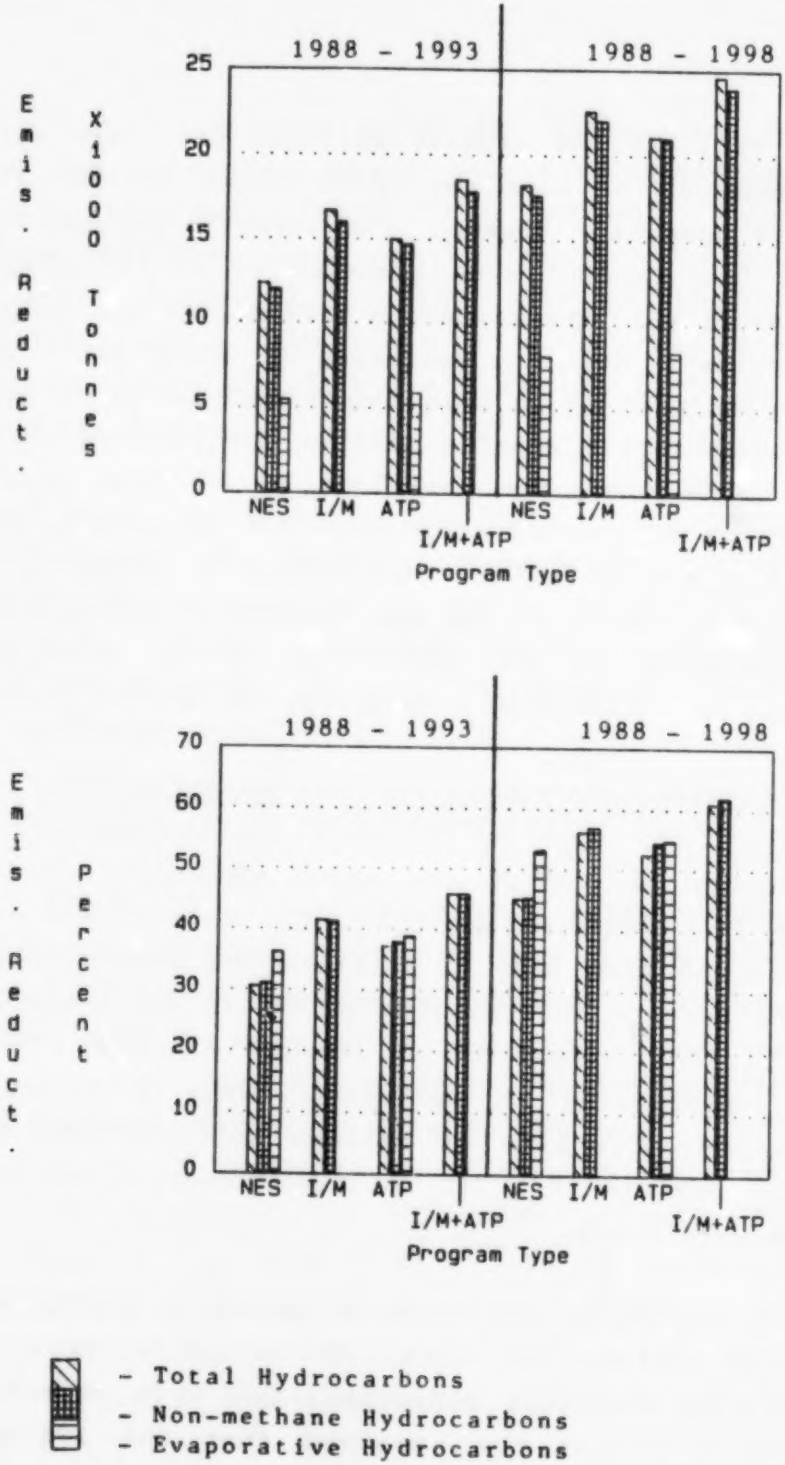


FIGURE 7.7: Percentage Reduction in Hydrocarbon Emissions from Light Duty Gasoline Vehicles Under Different I/M Program Scenarios After 5 and 10 Years (From 1988 Baseline Emissions)

mentioned earlier, the exhaust emission test used in an I/M program does not measure any hydrocarbons emitted from the evaporative sources. However, the computer program MOBILE3C does take into account some benefits of an I/M program, in terms of decline in the tampering rate of PCV and Evaporative Control systems. Thus the estimated HC values shown in Table 7.10 are presumed to include some reduction in HC emissions from the evaporative sources with an I/M program only. The estimates show that the emissions of HC from evaporative sources could be reduced through an ATP program by about 3% and 2% in 5 and 10 years respectively in addition to that expected as a result of the new vehicle emission standards. Maximum benefits in the reduction of HC emissions are expected to be achieved by a combined I/M and ATP program.

7.3.4 Misfueling and Excess Hydrocarbon Emissions

As misfueling is one of the major causes of increase in emissions from vehicles equipped with catalytic converters, an attempt has been made to estimate the impact of reducing misfueling rate on the emission of THC in the Lower Mainland area. In the estimation of overall emission factors by MOBILE3C, misfueling is estimated using a formula which increases with the rate of mileage accumulation, for each model year vehicle[130]. The estimated average for the fleet is approximately 13%.

To isolate the excess THC emission caused by misfueling alone from other causes, the total THC emission from vehicles equipped with catalytic converters has been determined for each year. It has been assumed that the 13% of these vehicles are habitually misfueled and the excess emissions resulting from such action are 2.47 g/mile and 1.57 g/mile for oxidation catalyst- and three-way catalyst-equipped vehicles[56]. These emission factors have also been used in

MOBILE3C[130]. In the absence of any information on excess emissions due to oxygen sensor damage by misfueling, this factor has not been taken into account. All other assumptions regarding fleet composition, vehicle population, average miles travelled are the same as those used in previous estimations. The estimated excess THC emissions as a result of misfueling during the period 1988 to 1998 are shown in Table 7.11.

It appears that for a misfueling rate of 1% of the whole fleet the overall THC emission from in-use vehicles would increase by approximately 0.4% and 0.6% in 1993 and 1998 respectively. These increases would result in total area-wide THC emission increases of about 0.1% and 0.2% in the corresponding years.

7.4 Target Reduction in Hydrocarbon Emissions

A recent study[131] on the O_3-HC-NO_x relationship in the Lower Mainland area has indicated that a reduction in the peak 1-hour average O_3 concentration could best be achieved by reducing the quantity of HC emitted in the area. The investigators have used the model OZIPM2/EKMA-CB3 of EPA and the 1978 emission inventory data as the base. It has been estimated that a 1% reduction in HC emission corresponds to a 1.7 ± 0.6% reduction in the peak 1-hour average O_3 concentration in the area from a base O_3 concentration of 0.20 ppm (1-h). It should be noted, however, that these estimates are very preliminary and based on several assumptions in the absence of any reliable and up-to-date information.

TABLE 7.11

Estimated Excess Hydrocarbon Emissions Due to Misfueling at a Misfueling Rate of 1% of the Lower Mainland Fleet

Year	Increase in THC Emissions		
	tonnes	%	
		of Light Duty Gasoline Vehicles	Of Total from All Sources
1988	81	0.21	0.08
1993	105	0.39	0.12
1998	125	0.61	0.16

Notes: Based on the fleet technology mix shown in Table 7.3 and EPA's excess emission factors for habitual misfueling . An average misfueling rate of 13% for the total fleet has also been assumed.

8. DISCUSSION

It is obvious from the information provided in the preceding sections that the control of ozone by means of an I/M program is doubly complicated. The formation of ozone, a secondary pollutant, itself is a complex phenomenon involving a number of chemical as well as certain uncontrollable physical variables. And the I/M program is not only a relatively recent and still evolving control measure, but also a conglomeration of technical and non-technical features.

The fact that an I/M program can be effective in reducing some emissions from vehicles, which constitute a large sector of similar source, appears to be the primary reason for its implementation in the U.S.A. in air quality non-attainment areas for CO and O_3. There are indications that such programs have been more effective in improving air quality with respect to CO than in reducing the O_3 level in the ambient air[28, 55, 132]. The air quality data analysis from certain non-attainment areas indicate some improvement, especially in those areas with very high O_3 levels[132]. Such declines in O_3 levels, however, do not appear to be concomitant with either the overall THC emission reductions or the designed values for respective O_3 reductions, including that expected from the I/M program[28, 55, 108, 132]. Despite these observations, some form of an I/M program to control emissions of O_3 precursors from motor vehicles is still regarded by EPA and others as one of the viable control strategies in certain areas[76, 105, 110, 119, 132].

Prior to recommending an I/M program option suitable for the Lower Mainland area, it is considered appropriate to recapitulate briefly the effectiveness of a conventional I/M program in controlling emissions of ozone precursors from motor vehicles.

8.1 I/M Program Strategies and Ozone Reduction

Since 1980 the ozone air quality in the U.S.A. has improved by about 10% on a national basis.[132] Despite the introduction of so many I/M programs and other control measures, even now more than one-third of the population there reported to live in O_3 non-attainment areas[132].

The uncertainty of THC control effectiveness of a conventional I/M program has existed in some quarters for some time. According to Elston[55] the implementation of such programs in various states has to a large extent resulted from the threat of sanctions by EPA under the Clean Air Act. Presumably such reluctance in certain quarters has resulted from the fact that the exhaust emission test used in a conventional program does not account for about 40-45% of the HC emissions through evaporative systems in a motor vehicle. Also since 1981 the introduction of vehicles equipped with new emission control technology, has created the need for a different approach to the design of an I/M program.

In the last few years, EPA has been encouraging inclusion of some form of anti-tampering and misfueling program (ATP) in the existing I/M programs to achieve additional benefits in emission reductions[56]. EPA has also granted SIP approvals to several ATP programs only in recent years, as mentioned earlier. Last year EPA announced that new measures including "enhanced I/M programs" were being evaluated to increase their effectiveness in controlling O_3 precursors emissions[110, 132]. However, no details on these measures are available yet.

8.1.1 I/M Program Options

There are several options available to an implementing agency for consideration on the general type of I/M program as well as on the program elements. Instead of being repetitious only the feasibility of the program types are discussed here, and the major elements of the suggested program will be outlined under appropriate sections.

The options seemed to be feasible for the type of I/M program are:

1. Public information campaign plus an industry-wide mechanic education program
2. Roadside pull-over check
3. Emission testing
4. Inspection and tests for tampering and misfueling, and
5. Emission testing combined with anti-tampering and misfueling inspection.

Although the final choice on the type of program would depend on various area-specific factors, on the basis of the primary determinant, namely the program effectiveness, options 1 and 2 do not seem to be suitable. Of the other three options it could be stated option 5 appears to offer the maximum benefits, as it incorporates the features of options 3 and 4.

A public information type of program by itself would provide limited benefits in terms of emission reductions from motor vehicles. This should be incorporated as one of the elements of other program options, and be designed to address both the vehicle owners and the repair service industry.

A roadside pull-over type of program is not considered to be effective in reducing vehicle emissions, unless such checks are done at several locations on a regular basis. It is used by several jurisdictions to gather data on various aspects of an I/M program for design and compliance purposes. Its implementation as a regular program would appear to be ineffective for various reasons, but mainly because of potential adverse public reaction, poor sampling of vehicles for inspection, the quality of data generated, and the cost-effectiveness.

Options 3 and 4 are feasible, and their effectiveness has already been discussed in detail in Section 6. As mentioned above the last option seems to be the most comprehensive, but the cost associated with the incremental benefits needs proper evaluation. In the absence of any cost-benefit analysis at this stage, this option has not been evaluated further here; however its major components viz. options 3 and 4, are discussed in appropriate sections.

As regards as the manner of implementation of a program of this nature, it is preferable to adopt a phased approach because of the number of variable elements involved. Such an approach also provides a degree of flexibility necessary for full implementation of the program, and is discussed in a subsequent section.

For the program effectiveness a totally voluntary type is not suitable because of its uncertainness, as the participating vehicles may not constitute a representative sample of the fleet characteristics. However, it has its merits during a phased implementation as a means of introducing vehicle owners to the forthcoming program.

8.1.2 Recent Emission Control Technology and I/M Program Design

To comply with the new emission standards, the post-1988 MY vehicles are expected to be mostly fitted with the recent emission control technology in vogue. This technology has already been discussed earlier, but its salient features need to be emphasized because of its significance in the design of an I/M program. Instead of traditional mechanical-pneumatic engine parameter control devices used in older vehicles, new vehicles are equipped with microprocessor-based electronic controls, including various sensors, and with catalytic converters to control exhaust emissions. The proportion of these new technology vehicles in the Lower Mainland fleet will increase gradually over the years.

Vehicles equipped with the new emission control technology operate well, if the control devices do not fail or are tampered with or misfueled. Although it has been observed in the U.S.A. that most new vehicles are less likely to have component failures or be subject to tampering and misfueling, any of these occurrences can turn these vehicles into gross emitters. There appears to be a growing belief in that country that most of the emission reductions from new technology vehicles can be achieved by minimizing the incidences of tampering, maladjustment and misfueling.

It appears that two major elements of the conventional I/M program are affected by the introduction of the new technology. The idle test for exhaust emissions fails to detect many excess emitting vehicles, and it can not directly identify the misfueled vehicles. Also several of the new emission control devices may not affect the idle emissions, but they do have varying impacts on the emissions from the vehicle when it is driven.

Another element of an I/M program seems to be affected by the new emission control systems is the repair cost waivers allowed in majority of the programs. Although such waivers do not apply to the repair cost of tampered components in most programs, recent investigations by EPA have indicated that the low repair cost waivers, compared to the actual replacement cost of new devices, are possibly limiting the effectiveness of most of the I/M programs.

8.2 I/M Program Design and the Suggested Program Elements for the Lower Mainland

Ideally an optimum design of an I/M program for an ozone non-attainment area should be derived after consideration of various factors, together with a proper economic analysis of its cost-effectiveness compared to other control measures. The major factors which affect the design of such a program are:

- the current and projected emissions of O_3 precursors from the motor vehicles in the area,
- the target ozone reduction percent and the estimated reduction of hydrocarbon emission inventory,
- the vehicle fleet characteristics and the prevalent rates of tampering and misfueling in the area, and
- the current estimates of excess emissions from motor vehicles due to maladjustment, tampering and misfueling.

Unfortunately no reliable information on the above factors is available, and whatever information on some of them presented in this report is based on preliminary or rough estimates, and in some cases based on default values from the U.S.A. It is anticipated that reliable information on emission inventory and target ozone reduction will be available in the near future, and other information will also be forthcoming soon after.

Considering the above limitations, the terms of reference for this work and primarily on the basis of the available information on I/M programs presented in previous sections, the following suggestions are provided tentatively for a program of motor vehicle emission inspection and maintenance in the Lower Mainland area.

8.2.1 Suggested I/M Program and Its Major Elements

The primary purpose of instituting an I/M program is to ensure that it acts as an effective deterrent to tampering of emission control systems and certain engine parameters, as well as to misfueling. Considering the various factors which influence the program effectiveness, the main criteria for designing a program should be its simplicity and flexibility. Such features would enable easy implementation and enforcement of the program, as the latter appears to be the key to its success.

As far as the deterrence value of the program is concerned, there is no substitute for a visual inspection to identify incidences of maladjustment and tampering, and to detect the major misfueling indicator, a disabled fuel inlet restrictor. Thus an I/M program based on visual inspection should be a stronger deterrent than one that relies only on the typical exhaust emission testing for THC and CO. The visual inspection is also the most reliable means of identifying the state of the repaired components in a vehicle. To ensure adequate detection of misfueled vehicles, a test for the presence of lead in the vehicle tailpipe by an approved method could be incorporated into the program.

To bolster an I/M program as well as to ease its implementation, certain other supplementary measures could be taken to remove incentives for tampering and misfueling of vehicles. Such measures are not considered to be part of the program itself, but their implementation will aid in an overall effort to reduce excess emissions of ozone precursors in the Lower Mainland area. These measures are of legislative type, and are described briefly later in this section.

A summary of the recommended program objectives and suggested activities is provided in Table 8.1.

8.2.1.1 Program Type

In view of the information presented herein, a mandatory I/M program involving visual inspection for tampering and misfueling and a test for the presence of lead in the vehicle exhaust pipe is considered appropriate. The visual inspection is a straight forward technique, and it can be applied uniformly after an initial period of familiarization with the inspection procedure. It is simpler than the exhaust emission testing by a short test because:

- as opposed to short emission tests it does not involve standardized test procedures and emission analysers, and thus a potential major source of quality assurance and enforcement problem is minimized,
- there is no need for establishing and justifying emission standards or cutpoints for various model year vehicles,
- it is not necessary to set an arbitrary stringency factor for vehicle pass/fail criteria, and
- one of the reasons for the repair cost limit or waiver, which in fact can defeat the purpose of an I/M program to a certain extent, is eliminated.

TABLE 8.1

Summary of Recommended Objectives and Suggested Activities for an Anti-tampering and Misfueling Program for the Lower Mainland

Program Objectives

Reduce incidence of tampering

Reduce incidence of maladjustment of certain engine parameters

Reduce incidence of misfueling

Proper maintenance of vehicles, and diagnosis and repair of malfunctioning and/or tampered engine parameters and emission control devices

Identify and require proper repair of tampered and misfueled vehicles

Reduce improper and unnecessary repair works and parts replacement

Control of fuel volatility to reduce evaporation loss

Effective enforcement of the program, efficient data management, data analysis, and quality assurance.

Increased and effective air quality monitoring program for the area

Assistance to the vehicle repair industry for better understanding of the program goal and the need for adequate training of mechanics

Assistance to the public to develop proper awareness of the problem and understanding of:
- -the program objectives
- -the importance of individual roles in proper maintenance of vehicles
- -the benefits of an improved air quality, of well maintained vehicles, and of fuel economy
- -the consequences of tampering and misfueling of vehicles
- -the manufacturers' warranty limits and conditions

Suggested Activities to Accomplish objectives

Effective enforcement of existing Acts and Regulations and introduction of appropriate legislations prohibiting:
- -sale and use of new light duty vehicles without certification,
- -sale and use of vehicles without adequate and properly operating emission control systems and related accessories,
- -any act of maladjustment or tampering of engine parameters related to vehicle emission and emission control devices and related accessories,
- -sale and use of unauthorized emission control devices and accessories as a whole or part to replace any equivalent damaged devices and accessories.

Effective enforcement of existing Acts and Regulations and introduction of appropriate legislations for:
- -the vehicle manufacturers to affix an approved label at the time of manufacture containing the required information on certain engine parameter adjustment specifications, emission control systems identification and their location, etc.,
- -the vehicle manufacturers to design and install appropriate limits, stops or seals on certain engine parameters which are physically adjustable,
- -the vehicle manufacturers to issue a 5-year, or an approved mileage, warranty against the failure of emission control systems and other approved components,
- -the manufacturer's recall program due to any premature failure of certain engine components and emission control systems.

Effective enforcement of existing Acts and Regulations and introduction of appropriate legislations prohibiting tampering with the fuel inlet restrictor on a vehicle and any other acts of misfueling of a vehicle by its owner or any other person or by fueling station personnel.

Introduction of appropriate legislation to limit fuel vapour pressure (RVP) during summer months.

Training of vehicle inspectors to properly diagnose and identify maladjusted and tampered emission control components.

Training and certification of mechanics in the repair industry to properly identify and repair tampered and maladjusted components.

Training of inspectors to carry out the testing for the presence of lead in the vehicle tailpipe.

Selection and authorization of inspection and repair facilities.

Record keeping at the inspection stations as well as at the repair facilities in an approved manner.

Regular audit and surveillance by trained program enforcement staff of both inspection stations and repair facilities to detect improper activities.

Development of a data management system and analysis of data on a regular basis.

Analysis of air quality monitoring data on a regular basis.

Implement multi-media public information program to inform people of the program goal and objectives, their individual roles in attaining the goal, the potential benefits of the program, and to assist them in identifying inspection stations and certified repair facilities.

Investigate any public complaints.

Conduct tampering and misfueling surveys in the area at regular intervals to determine the program effectiveness.

Review the data on a regular basis and implement necessary changes to make the program more effective.

As discussed earlier, the effectiveness of the conventional I/M program in identifying excess emissions from vehicles of recent model years is coming under some questioning. Moreover, to pass the reinspection by exhaust emission testing a vehicle does not necessarily require all its disabled components repaired properly.

The basic advantages of an anti-tampering and misfueling program as suggested above are:

- it focuses directly on the causes of excess emissions from a vehicle, and
- the excess emissions of evaporative HC from disabled PCV and evaporative systems, as well as that of NO_x from a tampered EGR can be identified.

The disadvantages of such a program appear to be a lack of proof that excess emissions from a vehicle are curtailed after the repair work. Also a slightly longer inspection time is necessary as compared to that required for exhaust emission testing by a short test.

The program should be introduced in a phase-in manner as a pilot program at the initial stage with some of the major elements of a full-scale program. As the majority of the basic information necessary for the design and implementation of a full-scale program is not presently available, the phase-in approach is considered to be the most appropriate. This approach can avoid the potential pitfalls of a hastily implemented program, and it offers several advantages, some of which are:

- gathering of necessary information for the actual program design and cost analysis including its cost-effectiveness,
- flexibility to revise program elements,
- generation of public awareness about the forthcoming program,
- allows time to notify and prepare the vehicle repair industry,
- initiation of mechanic training program,
- training of inspectors and enforcement personnel,
- selection of inspection facilities,
- determination of emission control components requiring inspection for different model year vehicles,
- establishment of both inspection and enforcement procedures and guidelines, and
- drafting and implementation of necessary legislation.

8.2.1.2 Program Phases

The mandatory program implementation should be made in three phases as follows:

Phase 1 - During this preliminary phase various government agencies, private garages and repair service industry, and other interested groups should be contacted to advise and seek assistance in the implementation of the upcoming I/M program. An effective public information program should be launched at this stage and continued throughout the program life. This phase is also essential for the design of the pilot program as well as for work on necessary legislations, selection of a few inspection facilities, training of mechanics, inspectors and enforcement officers, etc. The duration of this phase should be 9-12 months.

Phase 2 - This should be a voluntary phase-in period for the vehicle owners, during which time the inspections are performed free of charge. A limited number of inspection facilities could be established for this purpose to acquaint the vehicle owners, inspection and repair personnel, and the agency staff with various program features. During this phase necessary revisions to the initial program elements and the design of other elements should be undertaken and completed.

Other preparatory tasks, such as licensing of necessary number of inspection facilities, additional mechanic and other personnel training, program management system, etc., should also be completed. The effectiveness of the public information element should be evaluated and revised as necessary. A period of six months is considered necessary for this phase.

Phase 3 - The mandatory I/M program should be implemented for an initial period of 5 years with a provision for an extension if necessary.

8.2.1.3 Major Elements of the Suggested Program

As the characteristics of the major features of an I/M program have already been discussed at length in an earlier section, only outlines of the major elements of the suggested program are presented here. Moreover, the designing of the pilot program requires some additional information. Thus any recommendations on specific criteria for the elements would be speculative and premature.

Because of the suggested phase-in approach for the program implementation, not all elements listed require immediate inclusion in the pilot program. The only element which should be implemented from the outset is the public awareness program. Others could be modified to suit the initial need and used to generate data required for the main program design.

Inspection Facilities - As required under the terms of reference a decentralized program operated by private inspection facilities could be implemented. However, adequate agency enforcement would be essential for the program to be effective.

Inspection Frequency - As the existing systems of vehicle registration and insurance renewal are on an annual basis, it may be advantageous to have the vehicles inspected annually.

Vehicle Exemptions - Without pre-judging the final design on this item, it is suggested that initially only 5-year old and newer light duty gasoline vehicles, which constitute approximately 50% of the fleet population, should be included in the program as they are mostly equipped with new emission control technology systems. Depending on the vehicle population survey and on the target design for hydrocarbon emission reduction, it may be advantageous to include light duty gasoline trucks of recent years instead of older automobiles. These trucks are required to meet similar emission standards as light duty gasoline vehicles from 1988+ MY, and it is presumed their emission control systems are similar.

Tampering Inspection, Misfueling Test and Pass/Fail Criteria - In general all emission control systems and related accessories as listed in Table 4.2 should be inspected for tampering. However, the final selection of components should be made after a decision on the vehicles of model years to be included in the inspection program is taken, and a list of such components installed in those vehicles is prepared. Perhaps separate lists of these components for different model year vehicles and manufacturers could be drawn up for easy reference. An inspection manual or handbook should be developed for the inspectors to determine the necessity for and the location, as well as appearance, of specific emission control devices and related accessories in each type of vehicle.

As ignition and misfire problems are usually associated with excess hydrocarbon emissions and caused by maladjustments of engine parameters or faulty components, a test for such occurrences should also be included in the inspection. However, because these problems occur more with older vehicles, some consideration of this fact should be given in designing the vehicle exemptions element.

Besides the checking of fuel inlet restrictor for tampering, misfueling test for the presence of lead in the vehicle tailpipe by an approved procedure should be carried out. However, because of the possibility of so-called "false positives" and other inaccurate results being generated, some preliminary investigations and training would be essential before its implementation.

The criteria for passing or failing a vehicle should be determined on the basis of disablement of each specific emission control system, maladjustment of particular engine parameter, and positive test for the presence of lead in the vehicle tailpipe. Based on the inspection results, the vehicle owner may be advised about the repair requirements and a reinspection afterwards.

As some manufacturers have introduced on-board diagnostic warning systems for component failures in certain model year vehicles, the feasibility of inspection of such systems for failure should also be considered during the program design stage.

Mechanic Training - To increase program effectiveness as well as to assist the repair industry and vehicle owners, a mechanic training program is an essential element of the I/M program. Certificates should be issued to mechanics who successfully complete the training program at an approved institution and pass an examination conducted by the program implementing agency.

Public Information Program - A continuous public information program must be initiated to inform vehicle owners and operators of the need for and advantages of properly maintained vehicles in terms of individual and overall benefits to the society at large. The public should also be made aware of any penalties which may result from violation of any regulations on anti-tampering and misfueling. They should be assisted in their efforts to maintain vehicles in proper condition.

Inspection Cost - The determination of any fees for inspection and reinspection should await the final program elements design and a cost analysis study.

Enforcement - As the program is proposed to be a decentralized privately operated one and restricted to a relatively small area, a sticker-based enforcement system may be somewhat simpler than vehicle registration-based system. The latter usually involves dealings with another system run by a different agency. There are also certain potential problems with a sticker system; however, these could be avoided by proper auditing of sticker accountability, through adequate legislation and co-operation of the area police forces. The police forces in the U.S.A. reportedly do not like sticker enforcement. A final decision on the choice of enforcement system could be made after further evaluation.

Program Cost and Cost-effectiveness - As indicated earlier no attempt has been made to estimate the program cost and its cost-effectiveness. Such estimates should preferably be made on completion of the design for the program; otherwise any crude estimate based on the generic approach could be misleading. It is suggested that a study[5] contracted by Environment Canada, which is reportedly conducting a cost estimate for the subject area, should be consulted as it becomes available.

Agency Audit Requirements and Program Evaluation

In order for an I/M program to be effective in reducinng vehicular emissions, it is extremely important that program elements are implemented properly and equitably. The proper operation of any program depends upon identification of operating problems and institution of necessary corrective steps. This is usually accomplished by incorporating a comprehensive audit and quality assurance system into the I/M program. Such a system should be a dynamic process for achieving the desired benefits from the program.

Accurate collection and reporting of data are essential elements of an audit system. To generate the most useful information specific techniques need to be developed for key data collection and analysis. The quality control measures should include mechanic training, certification of mechanics and inspection stations, test procedure for the presence of lead in the exhaust pipe, training of agency personnel, inspection and test data recording and management system, etc. Auditing of inspection facilities and the quality of repairs should be the backbone of an I/M program.

It is suggested that as the implementation of the program would be a multi-agency effort, proper co-ordination of various activities should be a prerequisite for the program effectiveness. The roles of respective agencies should be clearly defined from the outset. Adequate agency personnel and resources must be allocated to ensure that program objectives are attained.

8.2.2 Supplementary Measures

Since the introduction of I/M programs the federal government in the U.S.A. has introduced several measures, not part of an I/M program, to aid the individual state agencies in program implementation. Some states have also taken additional steps to enhance the effectiveness of their particular programs. Most of these measures are legislated and active; certain others are presently under consideration.

To make the enforcement of an I/M program easier and to maximize the overall effectiveness of an ozone control strategy, the following supplementary measures are outlined for consideration. These activities will consist of drafting of new or revised legislations by appropriate authorities.

8.2.2.1 Anti-Tampering and Misfueling Legislation

The existing Motor Vehicle Act and Regulations pursuant to that should be amended to include prohibitions against disablement of specific emission control components. It is also suggested that consideration should also be given for imposing fines for such offences.

8.2.2.2 Ignition/Misfire Problem

Local police officers should be given authority to stop any vehicle with visible exhaust emissions or any indication of misfiring problem and ticket the owner to have the vehicle inpsected at one of the inspection facilities within a certain period. It is suggested that appropriate authorities should enact legislation to empower the police forces.

8.2.2.3 Labeling by Manufacturers

The vehicle manufacturers should be required, at the time of manufacture, to affix a permanent legible label of a specified type and in a prescribed manner containing certain information on emission control and related components. The type of information necessary should be decided upon by the regulatory agency. Such a label would enable an inspector to identify maladjusted and tampered components. Mechanics in the repair industry would also benefit from the information to be provided on the label.

8.2.2.4 Manufacturers' Warranty and Recall

It is suggested that an appropriate legislation be developed to require vehicle manufacturers to provide the vehicle owners with a warranty against malfunctioning emission control components. Such a warranty should cover the useful life of a vehicle which is defined as 5 years or 80,000 km. Apparently most of the major manufacturers of vehicles sold in the country offer a similar warranty voluntarily at present[105]. Therefore, the implementation of mandatory requirement would be relatively easy.

A compulsory vehicle recall program in the event of a common failure of any emission control related component by the manufacturers should also be legislated.

Such requirements would relieve some vehicle owners from certain costs of component repair or replacement necessary not through their own fault.

8.2.2.5 Engine Parameter Adjustment

As maladjustment of certain engine parameters, even in vehicles of recent model years, is still one of the causes of emission increases, regulations similar to that in the U.S.A. should be considered for implementation[80]. The vehicle manufacturers shall be required to design and incorporate adequate limits, stops, seals or other means to inhibit adjustment of selected engine parameters, which are physically capable of being adjusted and may significantly affect emissions. Some examples of such parameters are idle fuel-air mixture, idle speed, and initial spark timing on both carbureted or fuel injected vehicles, the choke valve action parameters on carbureted vehicles, or any other components which may fall into this category.

8.2.2.6 Replacement Components and Catalysts

The repair industry often uses less expensive components not manufactured or approved by the particular vehicle manufacturer to replace the original ones. There is no assurance that such components will perform as effectively as that required by the vehicle manufacturer. This is a subject of concern especially with respect to catalytic converters and catalysts, and EPA has recently proposed an enforcement policy on this matter[133]. It is suggested that a similar policy could be implemented by the appropriate authority in the Lower Mainland area.

8.2.2.7 Fueling Station Enforcement

To prevent the act of misfueling at the source it is essential that adequate regulations be in place to provide the regulatory agency with the necessary authority for enforcement. The following suggestions may be considered in this regard.

Motor vehicles should be certified for use of leaded or unleaded fuel only to render the enforcement of any regulation which prohibits misfueling. An act of misfueling by either the vehicle owner or the fueling station personnel should be made illegal, and anyone guilty of such an act should be liable for a penalty. The penalty could be either monetary or mandatory replacement of the catalyst, depending on the circumstances. To deter such practice and also as a public warning, a notice advising individuals of the liability involved should be displayed prominently at all motor vehicle fueling stations.

The Texas Air Control Board's regulations[120] on this matter may be consulted. To minimize misfueling by vehicle owners, the state of Oregon prohibits self-serve gasoline dispensing[82].

8.2.2.8 Price Equalization for Leaded and Unleaded Gasoline

To reduce the incidences of tampering and misfueling some indirect incentives may be provided to vehicle owners by introducing measures other than penalties by law. One of the reasons for using leaded gasoline is the price difference between unleaded and leaded gasolines. By equalizing the prices of these two kinds of gasoline, the immediate financial incentive to misfueling would be removed. Therefore, consideration should be given to this aspect especially when the lead phase-down in gasoline program is not due to be completed before 1992.

8.2.2.9 Fuel Vapour Pressure Control

As discussed in an earlier section, the vehicular emissions are affected by the fuel compositon and its volatility. In particular the evaporatiave hydrocarabon emissions increase significantly, about 2 to 4 times, as the gasoline vapour pressure (RVP) increases from 9 psi to 12 psi. The increase in such emissions tends to be higher for carbureted vehicles than for those equipped with fuel injection system. Exhaust emissions of hydrocarbons and carbon monoxide also increase with the increase in fuel vapour pressure, but not as pronouncedly as evaporative hydrocarbons.

Since the release of preliminary test data by EPA in 1984, indicating significantly high evaporative emissions from recent in-use vehicles using commercial gasoline, concerns have also been expressed by the Motor Vehicle Manufacturers Association and others in the U.S.A. regarding the trends in the increasing volatility of the commercial gasoline[58,134-136]. In an ozone non-attainment area any reduction of the fuel volatility is ecpected to be beneficial, as the resultant decrease in hydrocarbon emissions would be mostly in the form of reactive species. Moreover, added bendfits would result from gasoline transfer operations in the area.

The State ofr California has a legal limit of 9.0 psi RVP for the summer gasoline, enacted recently as one of the measures to reduce ozone level in the affected areas[67]. In a recent speech the administrator of EPA indicated that the agency is also "actively" considering some controls on gasoline volatility in ozone non-attainment areas[132].

It is suggested that this option for hydrocarbon emission reduction should be further investigated for the Lower Mainland area when information on the current emission inventories becomes available.

9. CONCLUSIONS AND RECOMMENDATIONS

In recent years the problem of photochemical oxidants, as indicated by the ozone levels in the ambient air, has been a matter of some concern in the Lower Mainland area. The formation of oxidants is a complex, dynamic process involving major technical uncertainties. Two known main precursors of ozone formation - reactive hydrocarbons and oxides of nitrogen - are common primary pollutants emitted from a variety of sources. In the Lower Mainland area preliminary estimates indicate that automobiles are the single largest source of these contaminants.

The Lower Mainland Oxidants Committee in August 1984 recommended an investigation into the feasibility of an I/M program in the area. The Task Force appointed in June 1985 for this purpose after reviewing the available information has made the following pertinent observations, and is making certain recommendations for consideration by the Committee.

Most of the information available on the subject is from the U.S.A. where EPA considers an I/M program as one of the ozone control strategies, and have been requiring the states to implement it in air quality non-attainment areas for ozone. Similar programs have also been used to reduce carbon monoxide emissions from motor vehicles in non-attainment areas for carbon monoxide, and reported to have achieved some degree of success. Because of the complexities involved in the formation and dispersion of oxidants, no direct impact of any reduction of hydrocarbon emissions due to an I/M program on the ambient ozone level could be established. However, there are evidences of reduction in hydrocarbon emissions from motor vehicles in areas having an I/M program designed for that purpose.

While new motor vehicles are designed and manufactured to meet the applicable emission standards, it is not uncommon to find the emissions from some in-use vehicles well in excess of those standards. Such excess emissions result in most cases due to improper maintenance of the vehicle, inadvertent or deliberate maladjustments or tampering with emission control systems, and misfueling of vehicles equipped with catalytic converters. An I/M program is implemented to deter such practices, and thus to reduce excess emissions from in-use vehicles.

In considering the feasibility of such a program for the Lower Mainland area, the available information on the I/M programs in the U.S.A. has been reviewed. The effects of the introduction of new vehicle emission standards in September 1987, similar to those in existence in the U.S.A. since 1981, on the future reductions in vehicular emissions have been reviewed. Particular emphasis has been given on the I/M program design and its impact on the potential emission reduction from in-use vehicles equipped with emission control technology of post-1981 model years in the U.S.A.

There is an increasing trend in the use of electronically controlled, microprocessor based emission control systems on vehicles of recent model years. The general observations appear to be that while such vehicles perform well under proper maintenance, the emissions could increase significantly in the event of malperformance due to any of the causes mentioned earlier.

Based on this review and on the estimated reductions in emissions of ozone precursors due to the introduction of the new emission standards and three types of I/M program scenarios, an anti-tampering and misfueling type of I/M program has been tentatively suggested for the Lower

Mainland area. The primary reason behind the tentativeness of the suggested program is that adequate site-specific information is not presently available for any detailed design. It has been suggested that essentially the program should be simple and flexible, of decentralized type with adequate agency enforcement, and be implemented in a phased manner. Several supplementary measures in support of the program have also been proposed for implementation.

The lack of necessary information, as well as time, have precluded any cost estimates for the program or its relative cost-effectiveness in emission reduction with respect to other potential control measures.

In view of this, the following recommendations are put forward for due consideration.

1. An anti-tampering and misfueling type I/M program should be considered for the Lower Mainland area.

2. On approval of an I/M program for the area, the public information program and an industry-wide mechanic education program must be developed and implemented at the earliest opportunity.

3. The detailed design of such a program should be initiated by a multi-agency committee on approval.

4. All necessary information for the program design and cost study should be made available to the above committee, and if required, additional data should be obtained by local surveys.

5. Consultations with certain regulatory agencies in the U.S.A. on I/M program design and implementation aspects could prove beneficial.

6. The training and certification of inspectors, mechanics and agency audit personnel in respective areas should also be initiated at an early stage. As the training of inspectors and mechanics will be a more or less on-going process, local technical institutions may be encouraged to provide such facilities. A handbook for inspectors should also be written.

7. The program could be operated through the Ministry of Transportation and Highways on a day-to-day basis.

8. The effectiveness of the program should be evaluated regularly. The criteria for evaluation should include among other parameters the results of regular tampering and misfueling surveys and an updated emission inventory.

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